The Economics of the Sulfuric Acid Industry

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By

THEODORE J. KREPS

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Preface

This monograph comprises one of the results of a program of research initiated more than ten years ago at the suggestion and under the direction of Professor F. W. Taussig of Harvard University. Under his guidance I began an inquiry into the economic problems raised by the penetration of chemical processes into industrial technology, and that at a time when economic literature in the United States almost completely lacked even short journalistic accounts of such important branches of the chemical industry as those manufacturing sulfuric acid, alkali, or coal-tar dyestuffs.

After making a canvass of the scraps of economic data available in trade journals, scientific periodicals, technical treatises, and government documents, I spent the summer of 1926 visiting chemical plants in the United States, interviewing executives, and making a field study, having been granted a Frederick Sheldon Fellowship for that purpose by Harvard University. Some preliminary results I subsequently assembled in a doctoral dissertation completed at Harvard in 1928.

But the study involved so many factors of international competition, especially so far as the alkali and coal-tar dyestuffs industries are concerned, that the Bureau of International Research at Harvard University granted me a further appointment, as Laura Spelman Rockefeller Fellow, for the academic year 1928–1929, which I spent collecting materials abroad, especially in England and Germany. The unlimited access given to me at this time by the Interessengemeinschaft Farbenindustrie Aktiengesellschaft to their extraordinarily complete chemical library at Höchst-am-Main was especially helpful.

In 1930 the Committee on Economic Research of Harvard

University made a grant covering statistical and clerical assistance which enabled me to publish articles on chemical economics in the *Quarterly Journal of Economics* and the *Journal of Economic and Business History*. The aid thus granted in various ways by Harvard University I hereby most gratefully acknowledge.

For the period from 1931 to the present I am particularly indebted to the Council of Research in the Social Sciences at Stanford University which by annual grants of funds has enabled me not only to carry further the data-hunting and -compiling part of the project but also to publish, in addition to this volume, certain other essays forming chapters in George Galloway: *Industrial Planning under the Codes;* Norman Himes *et al.: Economics, Sociology, and the Modern World,* essays in honor of Professor T. N. Carver; and J. Viner *et al.: Explorations in Economics,* essays in honor of Professor F. W. Taussig.

This monograph is the first of a series of four volumes now contemplated in the field of chemical economics, the others being concerned, respectively, with the economics of the alkali industry in the United States, with international competition in the chemical industry (as illustrated in the coal-tar dyestuffs industry), and with the chemical phase of the Industrial Revolution.

An adequate expression of appreciation to the many technicians, businessmen, government officials, and colleagues in economics, both in this country and in Europe, who have given generously of their time and knowledge, is impossible. But I should be definitely remiss not to mention with gratitude Dr. Grinnell Jones, professor of Industrial Chemistry at Harvard University, and Mr. Francis J. Curtis, director of development of the Monsanto Chemical Company, who in its early stages read the manuscript of this monograph in its entirety and provided incisive, constructive criticism

and guidance. Above all I have been fortunate in receiving continuous support, advice, and encouragement from Professor Taussig. Needless to say, for errors of fact or of interpretation I alone am responsible.

THEODORE J. KREPS

PALO ALTO, CALIFORNIA
November 15, 1937

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I. Introduction

Sulfuric acid, so far as the general public is concerned, is likely to be no more than a name. It is not a product that is stocked on the shelves of retailers or on display in their windows. Railroad cars or trucks are rarely seen hauling it around. Even the factories wherein it is produced are usually at a safe distance from automobile highways and from centers of population.

Yet the sulfuric acid industry is indispensable to the maintenance and improvement of the American standard of living. Merely to name the industries in which sulfuric acid figures would almost be equivalent to making a catalogue of modern industry. It is largely consumed in the manufacture of fertilizers, illuminating gas, soap, storage batteries, paper, ink, lead pencils, steel, celluloid, artificial leather, a great many medicinals, cleansers, shoe blacking, and dyestuffs. Its use in the production of dynamite and other explosives makes it a contributor to the successes of modern mining operations and large-scale building of roads. Its employment for the processes of electroplating and electrodeposition helps to make possible the tin can, galvanized iron, and the luxurious chromium surfaces of modern automobiles, refrigerators, furniture, and the like. It is widely used in smelting processes, in most of the ceramic arts, in making soda water and syrups, and in the packing industry. Modern sanitation would be impossible without it. In the cleansing of wool and the process of cotton manufacture it is indispensable. Without it we should have to find other ways to purify and manufacture gasoline, kerosene, and other petroleum products. Hardly an object embodying the refinements of manufacture which

are the demands and proof of advanced standards of consumption ever reaches the consumer without having benefited at some stage directly or indirectly from the use of sulfuric acid.

Every person owning or driving an automobile is deeply indebted to the sulfuric acid industry. While he may know or have learned by experience that the liquid in his battery which inflicts such painful burns on his hands is sulfuric acid, only rarely does he realize that literally every other mechanism except such parts as are made solely of wood or glass have also required sulfuric acid in their production. The gasoline and the oil he uses, for example, and the petroleum from which they came, have ordinarily experienced several treatments with sulfuric acid. So have the steel and the copper. If the upholstery contains wool it has probably been dyed in an acid bath. Even the glossy finish of which the owner is so proud, the nitrocellulose lacquer, the chromium plating, and the artificial leather—all have at some stage or other of their elaboration probably used sulfuric acid.

As a chemical tool sulfuric acid is unsurpassed. Students of chemistry soon learn to recognize it as an all-round handy agent for effecting chemical transformations in the laboratory. Industrialists needing an acid always see first whether or not sulfuric acid will do the trick, for it is the cheapest per unit of chemical activity and chemical work accomplished. It will decompose most metals and other substances, neutralize alkalies, and remove organic impurities. Among many other valuable properties are those of low freezing point at certain concentrations, great avidity for water, and low volatility. All together it is a cheap, powerful, microscopic, and multitudinous tool in chemical disintegration and synthesis.

Industrially sulfuric acid has in recent years been produced in the United States in volumes ranging from four to eight million tons. Ordinarily its tonnage is five or six times

that of the total amount of copper produced, eight or nine times that of lead, and from ten to fifteen times that of zinc. Its value will range from thirty to sixty million dollars—in ordinary years equal to that of aluminum and more than twice that of silver. Yet, except among technicians, the amount of economic and political consideration given to sulfuric acid has been but a fraction of that given to aluminum and silver.

SULFURIC ACID AN INDEX OF CHEMICAL PROSPERITY

Even textbooks on economic history either ignore the industry or give extremely skimpy accounts. Yet, by investigators who appreciate the extent to which its use pervades modern industrial technique, the state of the sulfuric acid industry is regarded as "a useful index of the position of the chemical industry generally."[1] This contention was first made by the famous German chemist, Justus von Liebig, who, after demonstrating the importance of restoring certain plant foods, notably phosphorus, potassium, and nitrogen, to the soil, concludes his discussion of the usefulness of sulfuric acid by saying, "there is no manufacture which deserves greater attention on the part of our governments."[2] In so far as sulfuric acid shows the situation in the chemical industries generally, it represents a branch of manufactures that, while having only one-sixteenth of the establishments, employs one-ninth of the workers, pays one-ninth of the wages, buys nearly one-fourth of the raw materials (more than one-half of the fuel), creates one-sixth of the value enhancement, and sells one-fifth of the product by value that manufacturing does in general.[3]

[1] S. I. Levy, *An Introduction to Industrial Chemistry* (McGraw-Hill, New York, 1926), p. 188.

[2] Justus von Liebig, *Chemische Briefe* (4e umgearbeitete und vermehrte aufl.) (2 vols., C. F. Winter, Leipzig, 1859), I, 188.

[3] For a definition of the chemical industries and the computations leading to these results, see an article by Theodore J. Kreps, "On the Chemical Phase

Some writers not only regard the amount of sulfuric acid consumed as an index of prosperity in the chemical industries but assert that it constitutes a faithful index of the cyclical pulsations of industry generally. "In recent years in the United States," according to an official publication of the Bureau of Mines, "especially in the East, the demand for sulphuric acid in the chemical and metallurgical industries has been a sensitive and accurate barometer of general business conditions. This demand for acid responds much more quickly to a general slump or boom in the industrial world than does the demand for iron and steel.[4] In Great Britain, Lord Beaconsfield similarly used to say "that there was no better barometer to show the state of an industrial nation than the figure representing the consumption of sulphuric acid per head of population."[5] As will become evident later, this contention—while not capable of incontrovertible proof, inasmuch as production statistics are nowhere obtained with sufficient frequency to permit verification—is by no means wholly devoid of truth.

Indeed, according to some observers, "sulphuric acid is today one of the absolute prerequisites of civilization, ranging in importance next to if not with pig iron."[6] As another writer puts it, "the degree of a country's wealth and civilization may be measured by its consumption of sulphuric acid."[7]

of the Industrial Revolution," in *Economics, Sociology and the Modern World* (essays in honor of T. N. Carver, edited by Norman Himes) (Harvard University Press, Cambridge, Massachusetts, 1935), p. 156.

[4] A. E. Wells and D. E. Fogg, *Manufacture of Sulphuric Acid in the United States* (Department of Interior, Bulletin No. 184, Washington, D.C., 1920), p. 4.

[5] A. W. Ashe and H. G. T. Boorman, *Chemicals* (Resources of the Empire Series, "Introduction") (E. Benn, London, 1924), VII, xx.

[6] United States Tariff Board, *Chemicals, Oils, and Paints. Glossary on Schedule A* (Washington, D.C., 1912), p. 15.

[7] A. M. Gibson, "The History of Alkali Manufacture in Great Britain," *The Mineral Industry, Its Statistics, Technology and Trade* (New York, 1894), II (1893), 117.

These statements, while overstating the case somewhat, nevertheless acquire considerable plausibility for those who investigate and attempt to assess the extent to which the many qualitative improvements and refinements in modern production technique and in consumption requirements are dependent upon the liberal and varied use of sulfuric acid.

II. From Alchemy to Automatic Process

The date of the discovery of sulfuric acid is lost in antiquity. Ancient and medieval craftsmen, while understanding very little about the properties of their materials, are known to have hit upon a number of chemicals such as botanical drugs and galenicals, sulfur, natural dyestuffs and tanning materials, pigments, vinegar and alum, in short, items found in nature either ready to use or nearly so. Whatever preparation of chemicals took place consisted of processes based on rule of thumb, rarely if at all improved, and then probably solely because of some accidental observation. Thus sulfuric acid may well have been used in ancient and medieval chemical practice, though of course the standard acidulating tool then was vinegar (acetic acid).

The first record of sulfuric acid in the fragments of literature that have come down to us is found in certain writings of the eighth century attributed to the Arab, Geber, in which is mentioned a "spirit" possessing solvent powers that can be expelled from alum. Albertus Magnus in the thirteenth century probably knew it as *spiritus vitrioli Romani.* And the alchemists of the fourteenth century may not only have known how to obtain it, both by distilling alum and by burning sulfur, but probably valued it highly as their most powerful weapon[1] in effecting that transmutation of metals whereby they hoped to find the *materia prima,* or philosophers' stone, which would change other substances into gold and would heal all diseases.

At any rate, a century later the alchemist Basilius Valentinius in his *Revelation of the Hidden Manipulations* describes, as though it were a process long familiar, the manner

[1] Cf. Ellinor Drösser, *Die technische Entwicklung der Schwefelsäurefabrikation* (Klinkhardt, Leipzig, 1908), p. 11.

in which fuming sulfuric acid can be obtained from the distillation of green vitriol or copperas (an iron sulfate). And in his *Triumphal Car of Antimony* he records a second method of producing sulfuric acid, namely, by burning equal quantities of sulfur and saltpeter in moist air under a glass. During the next two centuries, however, this last process sank into oblivion, at least in England. Thus not until the year 1686, when the religious persecutions instituted by Louis XIV drove Lémery and Lefèvre out of France, was there brought into standard apothecary practice in England the production of sulfuric acid by boiling sulfur in glass retorts in the presence of niter.

DEVELOPMENTS IN THE EIGHTEENTH CENTURY

The increasing demand for sulfuric acid soon led to attempts to make it on a larger scale. One of the more successful was that of Dr. Ward of Richmond, near London, who conceived the idea of using rather large glass vessels capable of holding about sixty gallons, equipped with horizontal projecting necks, in which he placed small iron receptacles. In these, a mixture of eight parts sulfur and one part niter was started burning. The neck was then closed with a wooden plug, until combustion slackened, when fresh air was admitted. Sulfuric acid was formed by the absorption of the smoke in water at the bottom of the vessel. The operation was repeated until the acid was strong enough for concentration by heating in glass vessels. Ward called this product "oil of vitriol made by the bell," in order to distinguish it from the product obtained by heating metallic sulfates. As a result the price of sulfuric acid soon went down from 2*s*. 6*d*. (say, 60 cents) per ounce to 2*s*. (say, 46 cents) a pound,[2] i.e., from about $14,400 to about $960 a ton.

[2] G. Lunge, *The Manufacture of Sulphuric Acid and Alkali* (3 vols., 4th ed.) (London, 1913), Vol. I, Part I, p. 6.

A most significant improvement came a few years later when Dr. Roebuck in a plant near Birmingham, England, substituted lead chambers for the glass bell, a fact which has since caused this mode of producing sulfuric acid to be called the "chamber process." To this day no other material has taken the place of lead, despite such disadvantages as its weight, softness and pliability, low fusing point, and high price. No other metals or alloys of equal cost resist acid-gases and liquids so well or are so easily rolled into large sheets or any other desired shape. No other metals, even after the invention of autogenic soldering by Debassyns de Richemont in 1838, can be so easily fused together and made gas- and liquid-tight. Moreover, "even after a number of years, when the chambers have become quite worn out, the greater part of their value can be recovered by remelting the material."[3]

As a result of this improvement a number of lead-chamber works were started not only in England but on the Continent, where in Rouen, France, in 1774, on the advice of De la Follie, the process was speeded up by introducing steam into the lead chambers during the burning of the brimstone. In the meantime the size of the lead chambers grew steadily larger (Dr. Roebuck's chambers were six feet square), some, in fact, exceeding 1,400 cubic feet in volume,[4] so that sulfur and niter could be run into the chamber in small wagons. Thus, by 1790, sulfuric acid began to be manufactured and sold, and its price came to be quoted not by ounces or pounds but by the ton.

Up to 1790, sulfuric acid was used primarily for the recovery of gold and silver from plated ware, for dissolving copper, and for making Roman vitriol. In that year Dr. Home of Edinburgh showed that by the use of sulfuric acid the

[3] G. Lunge, *op. cit.*, Vol. I, Part II, p. 584.

[4] S. I. Levy, *op. cit.*, p. 196.

process of whitening linen cloth could be cut from seven or eight months to less than four. In fact, the use of sour milk (lactic acid), then in vogue, frequently had to be repeated so often as to require from twelve to eighteen months. In the year 1788 considerable impetus was given to the manufacture of sulfuric acid by Berthollet's application of chlorine to the bleaching of cotton goods, rags, and the like; and still more in 1798 by the discovery of bleaching powder by Tennant in Glasgow. Thus the expanding textile industries in Scotland and the growing metallurgical industries near Birmingham began to furnish a tonnage market in which sulfuric acid in 1797 was sold net at £54 (say, $270) per ton.

Concerning cost of production and technical efficiency of operations at that time, little is known except that both undoubtedly varied considerably. The yield of concentrated or rectified oil of vitriol varied from about 110 per cent to possibly 150 per cent of the weight of the sulfur (or brimstone), while the consumption of the niter varied from 10 per cent to 20 per cent of the weight of the sulfur.[5] (In modern practice the figures are 300 per cent and 1 per cent, respectively.) The importance of such variations in yield appears clearly when the fact is remembered that the cost of the sulfur was quoted at 2*d.* (4 cents) to 2½*d.* (5 cents) a pound and that of niter at 70*s.* (*circa* $16.50) to £5 ($25) per hundredweight. Differences in costs between the least efficient and the most efficient practices may in raw materials alone have amounted to more than $40 per ton of sulfuric acid. The Bealy and Radcliffe works near Manchester, with six chambers 12×10×10 feet in dimensions, burning weekly 1,386 pounds of sulfur and 198 pounds of saltpeter (or niter), obtained 800 pounds of concentrated acid. This represents a yield of 130 pounds of sulfuric acid for every 14.3 pounds of niter and every

[5] Oscar Guttman, "Early Manufacture of Sulphuric and Nitric Acids," *Journal of the Society of the Chemical Industry* (1901), XX, 5–8.

100 pounds of sulfur burned.[6] In Prestonpans, near Edinburgh, another factory in 1800 showed yields of 111 pounds and consumption of 13 pounds, respectively.

DEVELOPMENTS IN THE NINETEENTH CENTURY

The next important improvement in the manufacture of sulfuric acid was that of making the process continuous. In 1793 Clement Desormes demonstrated that a considerable saving of niter could be achieved if a continuous current of air were fed into the chambers. By a series of research experiments completed in 1806 he showed that the niter was merely a catalyst. In 1810 Jean Holker put into practical operation an apparatus whereby not only air but the sulfur dioxide which results from burning brimstone could be continuously fed into the chambers. Batch or intermittent operations began to be combined into a continuous process.

Among many other improvements that tended in the direction of automatic and continuous operation, two in particular deserve further mention. The first of these was the Gay-Lussac tower, perfected in 1827. In essence it is a tower in which the nitrogen oxides are recovered. "It saves not merely

[6] *Chemistry, Theoretical, Practical and Analytical as Applied to the Arts and Manufactures* (8 divisions, Mackenzie, London, no date, but probably 1877), Div. VIII, p. 933.

The anonymous writer of the article "Sulphuric Acid" in this chemical dictionary gives a table of costs on page 932 as follows:

25 tons of sulphur at £40				£1,000	0*s.*	0*d.*
7 tons of niter at £100				700	0	0
Coals				105	0	0
Wages and houses for workmen				250	0	0
Tear and wear				30	0	0
Rent and buildings				70	0	0
Cartage				40	0	0
				£2,105	0*s.*	0*d.*
Yield is 142,500 pounds of oil of vitriol at 6½*d.*	£3,859	17*s.*	6*d.*			
Less 10% discount	385	19	9			
				3,473	17	9
Say, the cost was £32 per ton and the selling price was £54 per ton net—Profit				£1,278	17*s.*	9*d.*

at least two-thirds of the nitre, but also a great deal (a quarter up to a third) of the chamber space; it increases the yield of sulphuric acid, and, moreover, prevents the escape of acid fumes into the atmosphere."[7] It is a curious fact that despite these obvious advantages, the tower was not generally introduced into industrial practice until a considerable scarcity of nitrate of soda occurred in the period 1868–1870.

The second improvement in the chamber process was the invention of the Glover tower in 1859. It takes the nitrous vitriol from the bottom of the Gay-Lussac tower, exposes it to hot burner gases from the sulfur kilns (these are thereby cooled to the right temperature for reaction in the chambers), causes the nitrous oxides to be recovered, and keeps the sulfuric acid up to the concentration required for its use in the Gay-Lussac tower. Whatever additional nitrous oxide is needed (since some nitrogen is lost) can be introduced, without any further apparatus, simply by adding nitric acid to the nitrous vitriol or by "potting" nitrate of soda. Moreover, all the sulfuric acid formed in the chambers is thereby increased in concentration so that it contains about 80 per cent of sulfuric acid instead of but 65 per cent.

The Glover tower thus brought about a considerable reduction in the cost of producing sulfuric acid, for it not only increased the yield of acid about one-sixth[8] but it made possible a considerable saving in nitrate and labor expense, as is evident from the table below comparing the experience of a large English plant in 1872 without towers and in 1876 with towers.

While price changes account for about half of the drop in costs from around $10.70 in 1872 to, say, $5.75, it is clear that the amount of sulfur consumed was diminished one-seventh and that of nitrate two-thirds. Despite these economies

[7] G. Lunge, *op. cit.*, Vol. I, Part II, p. 781.

[8] See *ibid.*, pp. 591, 592.

the Glover tower did not become a general fixture of chamber-acid plants in the United States until about 1890.

COMPARISON OF COST OF SULFURIC ACID*

Item and Quantity		Price per Ton	Cost without Towers in 1872	Cost with Towers in 1876
		£ s. d.	£ s. d.	£ s. d.
Pyrites—	0.98 ton Norwegian (containing .42 ton of sulfur)......	1 3 6½	1 3 0	......
	0.76 ton Spanish (containing .36 ton of sulfur)......	0 19 0	......	0 14 4
Saltpeter—	0.0393 ton	16 0 0	0 12 7	......
	0.0145 ton	11 0 0	......	0 3 2
Coal—	0.125 ton	0 4 0	0 0 6	......
	0.25 ton .	0 4 0	......	0 1 0
Wages			0 7 5	0 3 6
Overhead costs and repairs.			0 2 0	0 5 0
Total cost			2 5 6	1 7 2
Net cost per ton of sulfuric acid (60° strength) after deducting proceeds from sale of by-products.............			2 4 0	1 3 7

* From Drösser, *op. cit.*, p. 69.

By the end of the nineteenth century, therefore, the chamber plant had come to consist pretty uniformly of three parts: the Glover tower, in which the niter is liberated; the lead chamber; and the Gay-Lussac tower, which absorbs the niter in cold sulfuric acid to be returned to the Glover tower, thereby permitting indefinite repetition of the cycle of operations. Figure 1 indicates the success with which automatic continuity of process has been achieved. Thus the chamber process became "a continuously working one, and thus it was enabled to be what it now is, the foundation of the chemical industry and the measure of its extent."[9]

[9] C. E. Munroe and T. M. Chatard, "Chemicals," *Twelfth Census of the United States, 1900,* Vol. X (*Manufactures*), Part IV, p. 532.

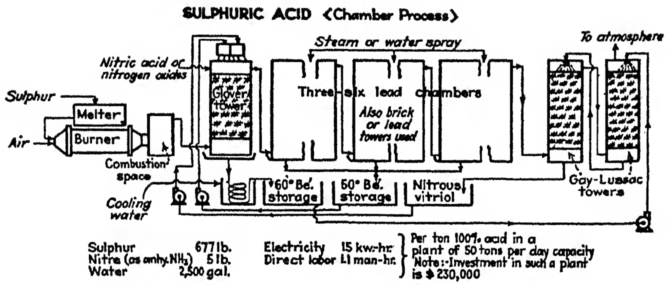


FIG. 1.—Flow sheet of sulfuric acid manufacture. From *Chemical and Metallurgical Engineering, Flow Sheets of Process Industries* (McGraw-Hill, New York, 1936), p. 47.

IMPROVEMENTS DUE TO SCIENCE OR EXPANDING DEMAND

The considerable lag which existed between the date of invention of these improvements and their adoption in industry must in part have been due to the dominance of rule-of-thumb procedure and attitude. It illustrates the tenacity with which practical men used to cling to customary technique. Research departments had not yet begun to bring about flexibility in processes, products, and markets. It required economic pressure such as the niter scarcity of the late 'sixties and early 'seventies or, in the usual instance, increased demand to stir industrialists to make general use of improvements.

The invention of the improvements, however, so far as the scientific history of the chamber process is concerned, does not seem to be nearly so closely bound up with the expansion of economic demand. The discovery of sulfuric acid by the alchemists, for example, occurred some hundreds of years before any considerable use for it had developed. It was the result of the science of the time. The first improvements, moreover, those of Ward and Roebuck, were made by doctors, a development quite natural in a period when chemistry and medicine were still so closely bound together as to lead

some historians to speak of an era of iatrochemistry. Again, despite the fact that the expansion in demand came in England and that the new plants were nearly all built there, it was in France that further important improvements were invented. Members of the French school of chemistry, followers of Lavoisier, were the first to publish researches on the process, Clement Desormes and, particularly, Gay-Lussac being names of scientific distinction. Except for the Glover tower, which appears to have been the happy idea of a practical operator, all or nearly all of the more striking improvements in the manufacture of sulfuric acid seem to have been the logical, one might say the quasi-inevitable, accompaniments or by-products of international scientific progress.

III. A Century of Small Enterprise, 1793–1890

The rudiments of a chemical industry in the United States existed even in Colonial days. Soon after the colonists landed they began to produce the salt which they needed for the household, for preserving fish, and for curing skins. They extracted potash from wood ashes (this comprised the chief chemical industry in the Colonies) and made lye, soap, and candles. They soon started the manufacture of a number of other articles then all regarded as chemicals—such as leather, lime, paper, sugar, rum and brandy, glass, iron, copper, naval stores, paint, saltpeter, and gunpowder.[1]

The promoter of many of these new enterprises was John Winthrop, Jr., who was "interested in the production of salt, iron, glass, potash, tar, black lead, saltpeter, copper, alum . . . . iron . . . . and dyestuffs."[2] He imported laboratory apparatus and chemicals in 1633, delivered papers on his enterprises before the Royal Society in London, and in 1649 was granted a monopoly by Connecticut for the working of lead, tin, copper, alum, and vitriol. From all this it seems more than likely that he knew sulfuric acid and that he made it, at least in sufficient quantities for his own use. He may well have been the first to do so. But if so, like other chemical enterprises of the period, his scale of operations must have been little larger than that of the apothecary's workshop.

Not until the end of the eighteenth century did the production of sulfuric acid acquire commercial proportions even of miniature size. In fact, the first person definitely known

[1] For an excellent account (based on original documents) of the numerous small enterprises which began to operate in the vicinity of Boston before the Revolutionary War, see Lyman C. Newell, "Chemistry in Old Boston," *Bostonia* (The Boston University Alumni Magazine), Vol. IV, No. 2 (May 1930).

[2] Lyman C. Newell, "Colonial Chemistry—I. New England," *Journal of Chemical Education* (March 1925), II, 163. See also "John Winthrop, Founder of the American Chemical Industry," in *Chemical Industries*, supplement of May 1935, pp. 5–9.

to have been successful in producing sulfuric acid for profit was John Harrison,[3] who began operations in Philadelphia in 1793. Having finished "his early education in Philadelphia, he spent two years in Europe investigating the arts and processes of the manufacture of chemicals and in studying under the celebrated chemist, Dr. Joseph Priestley."[4] Upon his return, he began to merchandise drugs and chemicals. In 1806 he sold his drug business in order to devote his entire attention to his manufacturing operations. In that year he began the manufacture of white lead. Later he added apparatus for making pyroligneous and acetic acids and their products, white and brown sugars of lead, also oxides of lead, colors, alum, copperas, iron liquors, and so forth.

SPREAD OF SULFURIC ACID MANUFACTURE FROM PHILADELPHIA

The success of Harrison led other druggists and manufacturers in Philadelphia to try their hand at sulfuric acid manufacture. Thus Farr and Kunzi in 1812, Powers and Weightman in 1825, and Charles Lennig in 1829 also began to produce the acid. The last-named appears to have gone into the business on a large scale, "putting up extensive leaden chambers, and concentrating the acid in platinum vessels so arranged as to be kept constantly at work while discharging

[3] "In 1793 he had a lead chamber capable of producing 300 carboys of acid per annum. The business proving very remunerative, he built, in 1807, a new lead chamber 50 ft. long, 18 ft. wide and 18 ft. high. This was a large chamber for the time and was capable of making nearly half a million pounds of sulphuric acid annually, the price of the acid being then as high as 15 cents a pound. Mr. Harrison was also the first person in the United States to use a platinum still for the concentration of the acid, this having been up to then done in glass, a very precarious and dangerous operation. This first still was made in 1814 by Dr. Eric Bollman, and was at once put in use. It weighed 700 ounces, had a capacity of 25 gallons, and was in continuous use for fifteen years." C. E. Munroe, "Chemicals and Allied Products," *Census Bulletin No. 210* (United States Department of Commerce and Labor, Washington, D.C., 1908), p. 8.

[4] Philip de Wolf and E. L. Larison, *American Sulphuric Acid Practice* (McGraw-Hill, New York, 1921), p. 2.

a steady stream of concentrated acid."[5] In 1834 another Philadelphia firm, Carter and Scattergood, began the production of hydrochloric, citric, and tartaric acids. During the next decade other large plants, such as those of John R. Savage and Company and Moro Phillips at Frankford, Buck Simonin and Company and Potts and Klett at Camden, were established in the vicinity of Philadelphia.

The industry gradually spread so that most of the larger cities in the United States had a sulfuric acid works. The Maryland Chrome Works and the Baltimore Chemical Manufactory began operations in 1829, both of them probably consuming the acid they made in the production of chromates, which were then used as dyes and pigments. In the same year Mr. William Davison started producing it, probably in part to supply his requirements for the production of ferrocyanides and other chemicals. Another consumer of sulphuric acid was the copperas and alum works founded by Richard Colton at Cape Sable, Maryland, in 1814 and operated for a time by the able Dutch chemist and geologist, Gerard Troost.[6]

As early as 1824 a New York company was organized to produce chemicals. In its charter it was stated that "the aims were to be the manufacturing of blue vitriol, alum, oil of vitriol, aqua fortis, nitric acid, muriatic acid, alcohol, tartar emetic, refined camphor, saltpetre, borax, copperas, corrosive sublimate, calomel, and other drugs, medicines, paints, and dyer's colors."[7] The statement shows rather clearly that the chemical industry of the time was closely bound up with the drug and medicinal trade.

[5] E. T. Freedley, *Leading Pursuits and Leading Men* (E. Young, Philadelphia, 1856), p. 172.

[6] M. I. Wilbert, "Early Chemical Manufactures," *Scientific American Supplement* (September 3, 1904), Vol. 58, pp. 23974–75.

[7] *History of the Chemical National Bank* (privately printed, New York, 1913), p. 136.

The history of the New York Chemical Manufacturing Company is interesting in other ways. It appears that the concern did some out-of-town business with New England and even New Orleans. Extracts from old order files read, for example, as follows: "Benedict and Company want by the first boat for New Haven 14 large carboys of oil of vitriol and one barrel of crude borax. H. Seymore of Hartford orders seven carboys of oil of vitriol by the Merchant."[8] Another interesting fact is that this chemical company, incorporated in 1823, obtained a banking charter the next year. By 1832, "the trustees transferred their main energies from the manufacturing of drugs to the work of exclusively establishing the credit and stability of their banking house"[9] (now the Chemical National Bank). Subsequently, while the business of handling dyers' and bleachers' chemicals, such as Glauber's salt, blue vitriol, epsom salts, logwood, and indigo, supplied predominantly from foreign markets, was continued, the sulfuric acid trade, proving unprofitable, was abandoned.[10] In 1844 the chemical business was given up altogether, the firm devoting itself wholly to banking.

SLOW GROWTH UNTIL AFTER THE CIVIL WAR

The growth of the sulfuric acid industry was slow. Chemically skilled workmen were hard to get. A certain amount of mystery and danger attached to the processes. The buildings were of peculiar and costly construction. Moreover, the de-

[8] *History of the Chemical National Bank*, p. 140.

[9] *Ibid.*, p. 6.

[10] Some quasi-journalistic accounts of the history of chemical enterprise call this episode "the earliest chemical price war." See, e.g., Williams Haynes, *Chemical Economics* (van Nostrand, New York, 1933), p. 169. But such an interpretation seems hardly warranted. Cf. C. E. Munroe and T. M. Chatard, *op. cit.*, p. 530, who give the original information thus: "A letter from Mr. Nicholas Lennig states that in 1829 his father, the late Mr. Charles Lennig, erected a sulphuric acid plant which 'was so successful that the then existing New York Chemical Company went into liquidation, and put the funds realized therefrom into a banking company now well known as the Chemical National Bank.'"

mand for the acid was relatively small. The rich agricultural, forest, and mineral treasures of a continent were available for seizure with scarcely any processing at all. Commerce and finance offered unparalleled opportunities. Consequently it was only here and there, and frequently by foreigners, that new sulfuric acid businesses were started.

One of these was the Grasselli Chemical Company, which began to produce sulfuric acid in Cincinnati, then the metropolis of the West, in 1839. Its founder was the son of a German producer at Mannheim, who is said to have been the first to utilize Sicilian brimstone in making sulfuric acid in the Old World.[11] Similarly, in 1840, next to their print works and the dye houses, "the Merrimac Manufacturing Company and the Lowell Bleachery, both Lowell cotton mills, built their own acid chambers, under the supervision of an Alsatian engineer."[12] By 1850 there were sulfuric acid plants in such scattered points as Roxbury, Salem, and Newton, Massachusetts; Providence, Rhode Island; Newark, New Jersey; Pittsburgh, Pennsylvania; St. Louis, Missouri; and New Orleans, Louisiana.

FERTILIZER MANUFACTURE CAUSES RAPID EXPANSION

In the third quarter of the nineteenth century progress in the sulfuric acid industry was quickened somewhat, the factor of greatest importance being the publication by Liebig in 1840 of his classical researches on plant nutrition. He demonstrated that the food of all vegetation is composed of inorganic or mineral substances. Up to that time the humus in the soil had been regarded as all-important. Once it was shown that leaves obtain their carbon from the air and that nitrogen, potassium, and phosphorus must be obtained

[11] "Chemical Industry's Contribution to the Nation, 1635–1935," Supplement to *Chemical Industries* (May 1935), p. 12.

[12] Merrimac Chemical Company, *Industrial Chemicals* (privately printed, no date), p. 7.

through the roots, the thought lay near at hand that so-called exhausted soils could be made fertile again by supplying these elements in water-soluble form.

In the late 'fifties, consequently, when the raising of cotton by extensive methods of cultivation east of the Mississippi began to reach the limits of available rich virgin cotton land, the South began to consider methods of intensive cultivation. The Civil War prevented any serious attention being given to the problem, but in the early 'seventies potassium began to be supplied from the German deposits at Strassfurt. Consumption of nitrogen was also increased, both in the form of ammonium sulfate, obtained by the action of sulfuric acid on the by-product ammonia of illuminating gas works, and in the form of Chile nitrates.

The plant food most cheaply and most readily supplied, however, proved to be phosphorus, obtained at first from imports of phosphate rock in the shape of Peruvian guano, which could be applied directly to the soil. That deposit becoming exhausted, the phosphate deposits of South Carolina began to be exploited. Later hard rock and land and river pebble of considerably higher grades were found in Florida and Tennessee. All of these deposits, however, furnished a phosphate rock that required treatment with sulfuric acid in order to change an insoluble tricalcium phosphate into the soluble superphosphate.

At first the rock naturally was shipped to the nearest sulfuric acid plant and was processed there and the resulting fertilizer was shipped back. Thus Dr. P. S. Chappell and William Davison, a founder of the present Davison Chemical Corporation of Baltimore, began to make fertilizers there in 1850. Baltimore being closest to South Carolina and to the Southern cotton fields, the established channels of trade in fertilizers soon came to focus there, although sulfuric acid plants along the whole northern coast line did a business in

acidulating phosphate rock that aggregated hundreds of thousands of tons until well into the 'eighties.[13]

Such an anomalous situation obviously could not endure. Soon scores of fertilizer plants were established in the South where they were not only near the raw materials but also near the market. According to reports of the United States Census Bureau, the number of establishments manufacturing complete fertilizers increased from 47 in 1860 to 278 in 1880, the value of their output increasing in that period from less than one million to nearly twenty million dollars. When it is remembered that the processing of a ton of phosphate rock uses up a ton of sulfuric acid, and that the amount of fertilizer produced as reported to the Census increased from 727,000 tons in 1880 to 1,898,000 tons in 1890, the size of the stimulus to expansion in the sulfuric acid industry begins to be appreciated. No wonder that by the year 1890 sulfuric acid plants subsidiary to fertilizer works liberally dotted the South, especially in the vicinity of such centers as Charleston, South Carolina; Wilmington, North Carolina; and Atlanta, Georgia.

The rapidity with which fertilizer manufacture grew in the 'seventies comes out clearly in the testimony of Mr. Joseph Campbell before the United States Tariff Commission in 1882. He states:

> I came over to this country in 1870 and have been mining in South Carolina. I do not think that 50,000 tons were mined in 1870; but today we are mining at the rate of 350,000 tons per annum. . . . . The manufacture of chemical fertilizers has been quadrupled in a little over a decade, for I do not suppose that more than 150,000 tons were manufactured in 1870.

The distribution of fertilizer manufacture and also of sulfuric acid production is indicated by the same witness, when he states:

[13] G. Lunge, "The Chemical Industry," *Mineral Industry, Its Statistics, Technology, and Trade during 1892* (New York, 1893), I, 1.

In Charleston, S.C., about 125,000 tons of chemicals are manufactured; in Wilmington, N.C., in Augusta, Ga., in Atlanta, Ga., and in Chicago, there is a large amount made; and Baltimore, I suppose, manufactures 150,000 to 200,000 tons; Philadelphia and Wilmington, Del., manufacture between them perhaps 150,000 tons. New England manufactures nearly 100,000 tons; New York over 100,000 tons.[14]

DEVELOPMENT OF DEMAND PRIOR TO 1890

In addition to the fertilizer industry there were a number of other industries whose rapid growth stimulated the expansion of the sulfuric acid industry. In 1859 Mr. Drake drilled the first oil well near Titusville, Pennsylvania. In thirty years the petroleum industry grew so rapidly that in the ten-year period from 1881 to 1890 an annual average of 29,249,000 barrels was produced. The consumption of sulfuric acid thus involved becomes evident when the fact is remembered that in order to produce eight gallons of kerosene about a pound of acid is required, that is, seven pounds per barrel or 3,500 short tons per million barrels. The growth of the textile, tanning, paint, and soap industries also meant an increasing direct and indirect demand. Alum, for example, was used in increasing quantities for dyeing, for the manufacture of paper, for tanning, for the manufacture of pigments called lakes, for water-purification, and so forth.

Toward the end of the 'eighties the sulfuric acid industry was growing very rapidly. As one important producer stated in 1882, "its manufacture has increased nearly 1000 per cent in the last ten years. In 1866 the price was 5 cents per pound, today it is 1¼ cents."[15] Yet the production of 1880 in 49 plants, according to the census figures, totaled but little over

[14] *Report of the United States Tariff Commission*, 47th Cong., 2d Sess. (House of Representatives, Miscellaneous Doc. 6) (2 vols., Washington, D.C., 1882), I, 330–31.

[15] Testimony of T. O. Armstrong of the Pennsylvania Salt Company, *Report of the United States Tariff Commission* (1882), I, 827.

one hundred thousand tons, worth less than four million dollars. This undoubtedly leaves out a considerable number of plants manufacturing sulfuric acid in which the main product was fertilizers or kerosene, for we find less than five years later a foreign observer reporting to his chemist colleagues in Great Britain:

> There are about 100 sulphuric acid works in the States. They are of all capacities from small works burning one ton of brimstone daily to large plants having an annual capacity of 20,000 tons of pyrites. The production of acid during the current year [1884] will reach 395,000 tons oil of vitriol . . . . [of which] 45% is used for oil refining, and 45% for fertilizers.[16]

PRODUCTIVE EFFICIENCY

Even at 1¼ cents a pound, or $25 a short ton, the price of sulfuric acid in the United States was still considerably above quotations in England. There they ranged from £3 ($15) a ton in 1878 to £2 ($10) a ton in 1886. The reason was primarily one of joint costs. In England more than three-fifths of the acid was used, and nearly all of it produced, in the Leblanc soda industry which dominated the chemical trade of the world from 1830 to 1890. Its main products, especially soda ash, soda crystals, and bleaching powder, not only were used in large quantities by Britain's textile industries but were exported to all corners of the earth and especially to the United States.

A typical Leblanc alkali works consisted of three parts: a sulfuric acid plant, a salt-cake plant, and an alkali plant. In the first, sulfuric acid was produced by the chamber process from brimstone or Spanish and Portuguese pyrites. In the second, the sulfuric acid was applied to common salt to produce salt cake, with a by-product of muriatic or hydrochloric acid which when absorbed in lime made bleaching powder. In

[16] William Martyn, "The Chemical Industry of the United States in 1884," *Journal of the Society of Chemical Industry*, IV, 26.

the third, the salt cake was calcined in the presence of limestone in an oven to produce soda ash, which by further treatment could be made into caustic soda. The sulfur-bearing residue from the lixiviation and purification processes was usually dumped on a waste heap near by. By a series of ingenious engineering devices and chemical innovations nearly all of the by-products were developed into profitable articles of commerce. Together all the products including sulfuric acid were produced more cheaply in Great Britain than they could be produced singly elsewhere.

Thus sulfuric acid was so much cheaper there than in the United States that as late as 1881 England exported phosphate fertilizer to the United States, i.e., phosphate rock was shipped across the Atlantic, processed, reshipped, and sold in competition in United States markets. The fertilizer and sulfuric acid producers protested with one accord before the United States Tariff Commission which was holding hearings in 1882. They petitioned for a tariff of $3.00 a ton on phosphate fertilizer, saying:

> The acids that are used to prepare the chemicals that are being imported free of duty really cost the foreign manufacturer nothing, being a by-product; and it does not stand to reason that the American manufacturers, with their expensive plant, large capital, and costly skilled labor, can compete with the foreign article that costs the compounder of artificial chemicals nothing . . . . [Moreover] in cases we have known of a whole cargo [of fertilizer] being brought as ballast, whilst if a manufacturer in Norfolk wishes to ship a cargo of similar goods from Norfolk to Savannah, Georgia, he cannot do it at a less cost than from $2.50 to $3.00 per ton, and yet the English manufacturer can load a cargo in Liverpool for Savannah at a sea freight from fifty cents to one dollar per ton.[17]

It is interesting to note that despite the protests of the sulfuric acid manufacturers, crude phosphates remained on the free list. And, similarly, sulfuric acid "which at the

[17] *Report of the United States Tariff Commission* (1882), II, 1397.

temperature of 60° Fahrenheit does not exceed the specific gravity of 1.380 for use in manufacturing superphosphate of lime or artificial manures of any kind or for any agricultural purposes,"[18] i.e., sulfuric acid of low concentration, has also remained on the free list to this day. Not so the concentrated acid or oil of vitriol. First mentioned in the tariff law of 1824 it carried a duty of 3 cents a pound. In 1842 this was reduced to one cent. It was put on an ad valorem basis in 1846, on the free list in 1861, was taxed at various rates during the Civil War, but was put back on the free list in 1872. There it remained until 1890, when a tariff of one-fourth cent a pound was imposed. While it was put imposed by the act of 1897. This was finally removed in the tariff act of 1913, since which time sulfuric acid of all grades has been on the free list.

Placing sulfuric acid on the free list in 1872 contributed toward the formation at Philadelphia in 1873 of one of the first trade associations in American industrial history. Seventeen of the largest sulfuric acid and chemical producers of that day formed the Manufacturing Chemists' Association of the United States. In Article II of its Constitution and bylaws the objects are stated to be: "1. Protection against unwise legislation and unjust freight discrimination. 2. When poson the free list again in 1894, the quarter-cent rate was again sible and proper, joint action of members through officers or committees of the association for the purchase of goods at reasonable prices. 3. To promote and aid any other general matter of general interest to the acid and chemical industries." Membership by election was declared open to "any oil of vitriol manufacturer and also any manufacturer of other chemicals whose annual production shall not be less

[18] For a table showing the tariff history of sulfuric acid and other chemicals from 1883 to 1909, see United States Tariff Board, *Chemicals, Oils, and Paints. Glossary on Schedule A* (Washington, D.C., 1912), pp. 255–74.

than fifty thousand dollars." An executive committee was created and empowered to "take charge of all business concerning tariff legislation, freight," and other matters. The major activities of the Association consisted of efforts to do away with disparity in average rates as between the chemical industry and manufacturing in general, to iron out tariff inequalities between various items in the chemical schedule, to obtain compensatory rates on finished products where duties were laid on essential raw materials, to secure equal consideration for their industry through education directed not only to the lawmakers but to thinking men in other industries and to the public as well, and to meet technical and economic problems with common action.

SUMMARY

Thus even in 1890 the sulfuric acid industry in the United States, while growing rapidly, had not yet reached a strong, independent, competitive stature. Most of the plants were small, many of them subsidiary to fertilizer or oil-producing establishments. Some were beginning to produce other articles closely tied up with its manufacture, such as nitric and muriatic acids, Glauber's salt, alum, nitrate of iron, and other technical specialties. The scale of operations was small, the average plant producing less than 4,000 tons yearly.

To be sure, the industry fully supplied the irreducible minimum of industrial demand, the three largest consumers in 1890 being the Virginia Carolina Chemical Company, the American Agricultural Chemical Company, and the Standard Oil Company. Such sulfuric acid as was indispensable for the purification of petroleum products, for bleaching cotton and linen goods, for the manufacture of fertilizer, dyes, and the like, was manufactured at home, for there were practically no direct imports of sulfuric acid. In fact, there hardly could have been, inasmuch as sulfuric acid of the strength then

available was very difficult to ship. Glass carboys had to be used. Even with the most careful packing, breakage in the unstable ships of the time was unavoidable, involving not only a loss of material but also serious damage and danger to cargo, ship, and crew. Thus in spite of the fact that the price of sulfuric acid in the United States was about double that in England, the domestic producer suffered but little direct foreign competition.

There was a good deal of indirect foreign competition, however. Imports of soda products grew rapidly during the period. So did the imports of dyes and other transportable chemicals which used large amounts of sulfuric acid in their manufacture. In some cases even where the raw materials, such as indigo up to 1825 and phosphate rock after 1870, were produced in the United States, the finished articles continued to be imported from abroad.

Needless to say, during the period from 1793 to 1890 all improvements in processes were first introduced abroad and not brought into practice here until considerably later. Thus Gay-Lussac and Glover towers were not generally used here until 1890. Moreover, though in England and on the Continent sulfuric acid producers began to burn pyrites, an iron sulfide and a cheaper source of sulfur, as early as 1838, most manufacturers in the United States continued burning brimstone or sulfur for another fifty years, despite the fact that many of the plants were started and run by persons who had brought their chemical skill with them from foreign shores. Thus the sulfuric acid industry, despite rapid growth after the Civil War, remained on the whole inefficient, imitative in its technique, rule-of-thumb in its methods, and at a distinct disadvantage in a country of unheard-of agricultural, mining, commercial, and financial opportunities. For the sulfuric acid industry the period 1793 to 1890 was a century of small enterprise.

IV. World Dominance

Since 1890 the triumphs of chemistry in the transformation of industrial technique in the United States have been so startling as to cause many observers to speak of a chemical revolution, or a chemical phase of the Industrial Revolution.[1] Industry upon industry has completely changed its processes, products, and markets through the deliberate and systematic application of chemical research to industrial practice. The metal industries with their hundreds of alloys, glass manufacture, tanning operations in the leather industry, pulp and paper manufacture, the cracking of petroleum into literally thousands of products, bleaching and dyeing of textiles, processes for purifying water, the vulcanization of rubber—these are but samples of the industrial operations which have been turned topsy-turvy since 1890 by the introduction of chemical control.

In addition, a host of new industries have been created, some of them duplicating natural products by chemical synthesis, others creating items entirely new. The shifts in international trade due to the invention of coal-tar dyestuffs, such as indigo and alizarin, and the resultant central position of Germany not only in coal-tar colors but in medicinals, military explosives, gases, and the like, are but one example. Consider, likewise, the numerous recent cartel and international governmental negotiations centering around Chile nitrate. Among the items entirely new, rayon, nitrocellulose lacquers such as Duco, compressed gases and acetylene, oleomargarine, and photographic film merely require mention to

[1] See, e.g., Williams Haynes, *Chemical Economics* (van Nostrand, New York, 1933), chapters x and xii; Edward R. Weidlein and William A. Hamor, *Science in Action* (McGraw-Hill, New York, 1931), chapters vii, viii, x, and xi; and Theodore J. Kreps, "Chemical Industry," *Encyclopedia of the Social Sciences* (New York, 1930), III, 365–67.

bring to mind the gigantic corporations of international scope producing and marketing them.

In industry after industry chemists have made available new raw materials, established new uses for old products, developed new products, and in general made the research laboratory the intelligence department and nerve center of the plant. Since the year 1888 when Du Pont's established the first industrial research laboratory near Wilmington, Delaware, their number has grown to more than 1,600, employing 35,000 workers at an annual cost of over $200,000,000.[2] Trained chemists set specifications for raw materials, apparatus, and finished products and control manufacture, distribution, and even ultimate use by the consumer.

In some cases the economic effects have been no less startling. Because of joint costs, because of the continual emergence of competing products made from cheaper raw materials and the development of new and cheaper processes, an efficient plant soon becomes obsolete. The balance of advantage of firms in any given market is at best precarious. Competition becomes sharper, universally and perhaps inevitably causing chemical industrial history to be increasingly characterized by the formation of international cartels and gigantic concerns integrating the manufacture of hundreds of products. Not demand and supply but financial and commodity *haute politique* carried on on an international scale determine at least in the first instance not only prices but production and sales quotas as well. Despite tariffs, partitioning of markets, agreements, patent pools, and other restrictive devices, the area of competition has relentlessly widened not only across political frontiers but vertically through stratum after stratum of industrial enterprise. Chemistry has made dozens of obscure or unknown substances be-

[2] C. M. A. Stine, *Change Rules the Rails* (The Chemical Foundation, Inc., New York, 1936), p. 13.

come items of considerable importance in international trade, weaving the world together in growing economic interdependence. Competition is no longer single-line and four-square. Increasingly it is becoming not only intercompany, but interprocess, interproduct, interindustry, and international.

The sulfuric acid industry illustrates par excellence practically all of the characteristic features of the chemical phase of the Industrial Revolution. It has shown amazing growth in the quantities produced with ever lowering costs and lower prices. Similarly it has witnessed the growth of new processes which have not only forced the old to improve or to be abandoned but have captured a good share of the market. Likewise the manufacture of sulfuric acid has been increasingly carried on not by one industry but by several. In only one does it constitute the main product. In other industries its manufacture is subsidiary, incidental, or compulsory. The competition that exists between areas is usually one of unique clusters of industries in which the production and sale of sulfuric acid happens to have a place, albeit in none quite the same place. Furthermore, the chemist has enabled sulfuric acid to be profitably made from several raw materials, some of which have fluctuated in their competitive status to an extent entailing governmental action by some of the leading powers of Europe. Again, in order to minimize the risks of competition, of obsolescence, of sudden invasions of markets, and the like, the sulfuric acid industry has witnessed the growth of gigantic concerns making an integrated range of products, utilizing fully their research facilities, raw materials, and technical supervision, and servicing a variety of markets. Moreover, no better illustration can be found of the way in which the lot of labor is affected by modern, large-scale, automatically operating chemical processes than a study of the occupational hazards, hours, wages, and duties

of labor in the sulfuric acid industry. Finally, the sulfuric acid industry, so far as the chemical phase of the Industrial Revolution is concerned, was not only passive but active. In many industries it became one of the most important agents of chemical transformation. The number of its uses increased many fold.

TENFOLD INCREASE SINCE 1890

The rapidity of the growth of the sulfuric acid industry is clearly shown by the heavy line on Figure 2. The steepness of the ascent of the curve, despite the fact that it is plotted

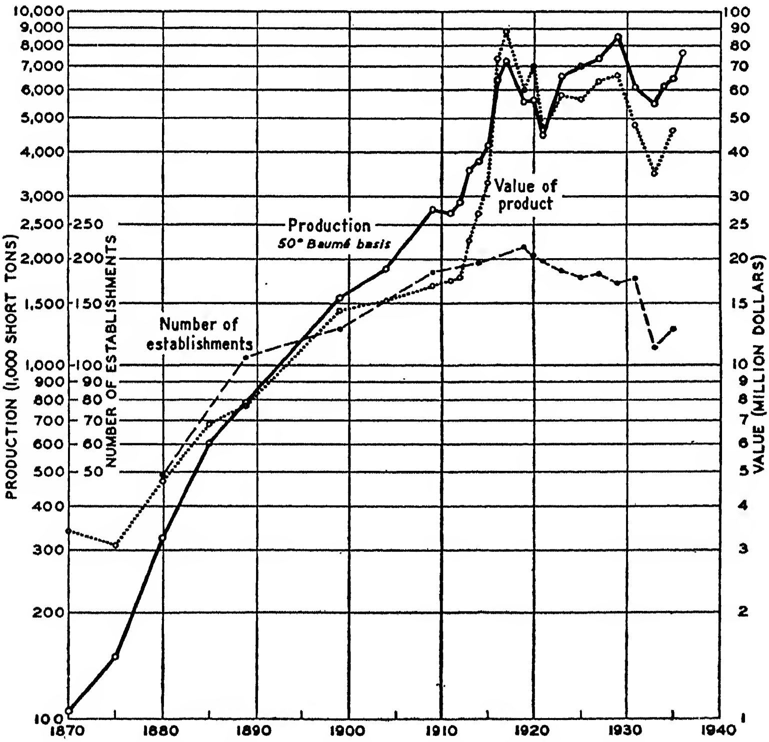


FIG. 2.—Growth of sulfuric acid industry from 1870 to 1936. For sources of data, see Table 1.

TABLE 1

PRODUCTION OF SULFURIC ACID IN THE UNITED STATES, 1865–1935*

Year	Quantity Produced 50° Bé. Basis (*Short tons*)	Value	Average Value per Ton (*To nearest ten cent figure*)	Number of Establishments	Quantity Produced per Establishment (*Tons*)
1865...	60,000[a]	$ 2,900,000[b]	$48.30	...	.....
1870...	105,000[a]	3,400,000[b]	32.40	...	.....
1875...	150,000[a]	3,100,000[b]	20.70	...	.....
1880...	325,000[a]	4,700,000[b]	14.50	49	6,600
1885...	600,000[a]	6,800,000[b]	11.30	...	.....
1889...	783,569	7,679,473	9.80	105	7,460
1899...	1,548,123	14,247,185	9.20	127	12,200
1904...	1,869,436	15,174,886	8.10	...	.....
1909...	2,748,527	16,779,195	6.10	183	15,020
1911...	2,688,456[c]	17,313,822	6.40	...	.....
1912...	2,876,000[c]	17,572,837	6.10	...	.....
1913...	3,538,980[d]	22,366,482	6.30	...	.....
1914...	3,762,417[e]	26,790,904	7.10	194	19,400
1915...	3,868,152[f]	32,657,051	8.40	...	.....
1916...	5,642,112[g]	73,514,126	13.00	...	.....
1917...	5,967,551[h]	87,540,181	14.70	...	.....
1919...	5,552,581	59,916,870[j]	10.80	216	25,700
1920...	5,602,403	69,916,455	12.50	204	27,460
1921...	4,369,941	45,972,400[j]	10.50	197	22,200
1923...	6,555,517	57,750,000[j]	8.80	185	35,400
1925...	7,004,112	56,540,000[j]	8.10	177	39,570
1927...	7,335,795	63,161,000[j]	8.60	181	40,500
1929...	8,491,114	65,869,000[j]	7.80	170	49,900
1931...	6,085,242	47,647,000[j]	7.80	175	34,770
1933...	5,475,000[k]	34,850,000[j]	6.40	112	.....
1934...	6,166,000[k]	....	....	...	.....
1935...	6,462,212	45,880,000[j]	7.10	126	51,300
1936...	7,620,000[k]	....	....	...	.....

* Figures for the years 1889–1904, inclusive, 1919, and 1921–1931, inclusive, were taken from publications in the respective years of the Bureau of the Census, entitled *Census of Manufactures* (title and department issuing this census change). Data for the years 1909–1917 and 1920 are taken from the annual publication of the United States Geological Survey entitled *Mineral Resources of the United States;* see in particular Volume II, *Non-Metals,* articles on "Sulphur," "Pyrites," and "Sulphuric Acid."
Dots indicate figures not available.

[a] Estimates given in an article by W. H. Adams entitled "Pyrites as a Material for the Manufacture of Sulphuric Acid," in the *Journal of Analytical and Applied Chemistry* (1931), V, 601. His figures are for 66° Bé. acid, but have been multiplied by 1.5 to reduce them to acid of 50° Bé. strength. The reliability of these estimates is evidenced by the figures for sulfur imports in chapter viii below. One ton of sulfur will produce

on a logarithmic grid or ratio scale, indicates how rapidly the total production of sulfuric acid increased from 1870 to 1935.[3] While the acid appears in various strengths, they can all be diluted to the lowest concentration customarily used in industry, technically called 50° Baumé acid, on which basis the census and the trade journals usually issue their figures for total production and on which basis the tonnage figures are given here. Note that the industry grew with extraordinary rapidity until the year 1917 (the peak of production was probably reached in 1918), and that since that time it has expanded relatively slowly. The two peaks of production,

[3] A word of caution in interpreting the charts in this chapter may not be superfluous. Individual curves are strictly accurate only for those years (marked by circles or dots breaking the lines) in which data are available. The straight lines joining these years do *not* show the actual course of events. They have been drawn merely to help the reader in finding adjacent points. A series of component bar charts, while more accurate, presents a much more cumbersome and less readily intelligible appearance.

from 3½ to 4 tons of 50° Bé. sulfuric acid. The census figures for 1870 are clearly inaccurate, listing only 4 establishments with a total product valued at $212,500. In the census for 1900 it is stated that "there were at least 25 sulphuric acid works in operation with a product of over a million dollars in value." The census figures for 1880 seem also open to doubt listing only 308,765,432 pounds of product to the value of $3,661,876. To reduce this to a 50° Bé. basis is impossible with accuracy, but 170,000 tons would seem to be a fair estimate.

[b] Computed from the index of sulfuric acid prices as given for the years in question in: United States Senate Committee on Finance, Report by Mr. N. W. Aldrich on *Wholesale Prices, Wages, and Transportation*, 52d Cong., 2d Sess. (Senate Report 1394) (4 vols., Washington, D.C., 1893).

[c] The quantity and value of acid produced as given in the year 1911 are exclusive of electrolyte and acids greater than 66° Bé.

[d] Exclusive of 22,947 short tons of fuming acid valued at $318,044 which, while not accurately convertible to 50° Bé. acid, probably represented about 40,000 tons 50° Bé. acid, making the total 3,598,000 tons.

[e] Exclusive of 21,993 short tons of fuming acid valued at $316,596 which, while not accurately convertible to 50° Bé. acid, probably equals 1.7 times its weight of 50° Bé. acid, or 37,500 tons; total, 3,790,000 tons.

[f] The quantity does not include 189,795 short tons of stronger acids not convertible to 50° Bé. acid but roughly equal to 323,000 tons; total, 4,191,000 tons.

[g] The quantity does not include 443,332 short tons of stronger acids not convertible to 50° Bé. acid but roughly equal to 753,000 tons; total, 6,395,000 tons.

[h] Exclusive of 759,039 short tons of stronger acids not convertible to 50° Bé. acid but roughly equal to 1,292,000 tons; total, 7,260,000 tons.

[j] Values are computed from census figures for unit value of the sulfuric acid sold (given in the third column).

[k] Estimates made by the staff of *Chemical and Metallurgical Engineering* and published in the January or February issue each year.

1917 and 1929, represent, respectively, war demand for explosives and peace-time demand for iron and steel, fertilizers, gasoline, and chemicals.

Note further that the curve of physical output of sulfuric acid does not furnish an adequate basis for establishing correlations of its variations with the fluctuations of industrial production or of business in general. Figures are available only for census years at periods too far apart to enable significant comparison with monthly time series. Nonetheless the two recent depressions unmistakably show production declining 22 per cent in 1921 from the figure of 1919 and 40 per cent in 1933 from the levels of 1929, a decline which is slightly greater than that shown by the Federal Reserve Board index of general industrial production, which went down from 83 on the average in 1919 to 67 in 1921 or 19 per cent, and from 119 in 1929 to 76 in 1933 or 36 per cent.

Turning now to the dotted line showing the value of the sulfuric acid produced, notice that it rises rapidly until the year 1900 and then tapers off until the war years, when it rises precipitously to an all-time high in 1917, the year the United States entered the World War. Despite a physical output 40 per cent larger in 1929 than in 1917, the total value of the sulfuric acid produced was more than 30 per cent less.

The explanation lies, of course, in the fluctuations of average unit value per ton which, as is shown by Column 3 in Table 1, fell very rapidly from $40.00 in 1865 to $9.20 in 1899. As will appear in the next chapter, interprocess competition, cheaper sources of sulfur, and other forces caused a further decline to a level around six dollars a ton. In the early part of 1914 sulfuric acid was almost a drug on the market; many plants had shut down completely.

During the spring of 1915, however, the demand for munitions began to make itself felt, and prices soared to levels in

1917 nearly two and one-half times prewar figures. From an average of more than \$12.00 in 1920 the unit value of sulfuric acid has slowly gone downward throughout the prosperous 'twenties until in 1929 it reached a figure below \$8.00 a ton and in 1935 one under \$7.00.

A word of caution is necessary. These computed averages show greater variability than do actual quotations in the trade journals. The reason, of course, is that the price differentials between dilute and less-dilute sulfuric acids vary considerably, as do the proportions between the amounts of the different grades produced and sold.

Finally, Figure 2 is instructive in that it indicates something of the manner in which large-scale production has grown in the industry. Notice that the narrow line, representing the number of establishments, while starting above the other two curves, soon falls below them, thence forming an ever widening gap. It reaches its high in 1919 and declines rapidly thereafter, with a terrific drop in 1933, the result of the cessation of production of sulfuric acid by numbers of small fertilizer plants.

Turning to the table, one readily understands why the figures of average quantity produced per establishment should show a five- to six-fold increase, growing from 8,700 tons in 1880 to over 51,000 tons in 1935. Such averages, of course, hide as much as they reveal, especially in the way of variation in size among individual plants. They also depend to some degree on the state of business, naturally being high in prosperous times. Nonetheless, they show an undeniable trend toward large-scale production.

AMOUNTS PRODUCED OF VARIOUS STRENGTHS

Sulfuric acid, while produced in several strengths, is ordinarily marketed in only four. These are commercially known as chamber acid testing 50° Baumé, tower acid or 60° Bé.

acid, oil of vitriol or 66° Bé. acid, and fuming acid or oleum, which is sulfuric acid containing free anhydride or sulfur trioxide. A table of important facts about these varying concentrations is given below.

TABLE 2

COMMON TECHNICAL GRADES OF SULFURIC ACID*

Technical Name	Percentage of Sulfuric Acid	Specific Gravity in Degrees Bé. at Temperature of 15° C.	Freezing Point, Degrees Centigrade	Chief Uses
Battery acid......	27.0 27.5	24	—36	Batteries
Chamber acid, or 50° Bé. acid	62.0 69.4	50.0 54.7	—48 to —63	Manufacture of phosphate fertilizers
Tower acid, or 60° Bé. acid	74.5 82.4	58.0 62.3	—40 to + 8	Pickling steel, tinning, galvanizing
Concentrated oil of vitriol, or 66° Bé. acid	91.9 95.6	65.4 65.9	—34 to —16	Manufacture of nitric and other acids, purifying petroleum
Oleum, 20 per cent anhydride	80.0	....	—11	Intermediates, dyes, explosives, nitrocellulose lacquers, etc.
Oleum, 40 per cent anhydride	60.0	....	0.7	

* Adapted from Levy, *An Introduction to Industrial Chemistry* (McGraw-Hill, New York, 1926), p. 192.

The technical reasons for the marketing of sulfuric acid in these four grades form "an excellent illustration of the difference in atmosphere between pure chemistry and industrial chemistry. . . . . [Precisely those] differences in the physical and chemical properties of sulfuric acid at various stages of dilution which have but slight significance in the

ordinary chemical laboratory become of the most vital importance to industry."[4]

Take, for example, the fact that dilute acid dissolves nearly every common material except lead, while strong acid may be safely heated for concentration in vessels of iron. The student working with glass or porcelain receptacles and with small quantities of the acid often fails to learn the dollars-and-cents value of using less expensive materials. But the industrial chemist striving for lowest possible costs must possess and constantly employ an exact knowledge of the properties of sulfuric acid in its various concentrations; he must know when the expensive glass, platinum, fused silica, or alloy in retorts can be safely replaced by vessels of lead or iron.

To the student the fact that at many concentrations sulfuric acid freezes rather readily is a property of little laboratory significance. But in the unheated plant or in shipping the acid in the winter time the freezing point becomes of crucial importance. Again, while he may notice the heat which is generated when the acid is mixed with water, he merely cools his test tube full in the open air or throws it away. But when the student becomes a supervisor in a plant he will find acid in bulk simply terrifying and uncontrollable in the wrong place, especially when tons of it need to be cooled down or are escaping from a corroded pipe or vessel.

The four strengths in which sulfuric acid is commonly marketed all have low freezing points and maximum transportability when properly packaged. Each is adapted to particular uses, so that the relative amounts produced, as shown on Figure 3, represent in part fluctuations in the status of consuming industries and in part the shifts in competitive advantage of the chamber process as compared with other processes (to be described in the following chapter).

[4] Levy, *op. cit.*, p. 188.

Turning to Figure 3, note that in 1889 practically all the acid produced was either chamber acid or oil of vitriol—

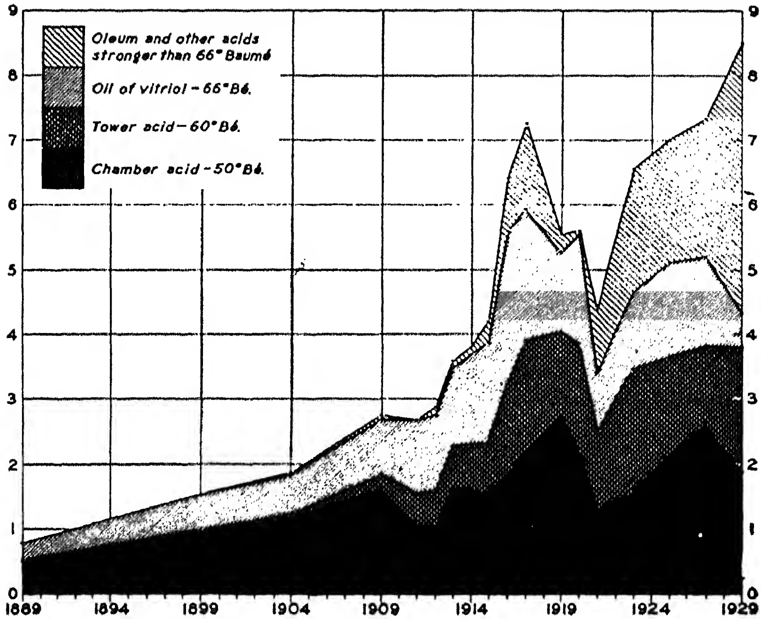


Fig. 3.—Production of sulfuric acid by strengths, 1889–1929 (million tons, 50° Bé. basis). For sources of data, see Table 3.

further evidence that phosphate fertilizer and petroleum refining were by far the two largest outlets at that time. The broadening toward the right of the bottom area indicates the gradual expansion that has taken place in the demand for chamber acid, an expansion reaching its peak during and after the World War when agricultural production in the United States (and hence the use of fertilizer) was stimulated to a maximum by European demands for cotton and foodstuffs. The widening of the unshaded portion immediately above, namely, that showing the production of tower acid, pictures in part the extent to which tin cans and galvanized

iron, among other things, have won a place in ordinary usage and in part the degree to which the use of Glover towers in the chamber process increased from practically nil in 1889 to quite general employment in 1929. Moreover, as will be explained in chapter vi, it also shows increasing production of by-product acid from the waste stack gases of zinc and copper smelters.

The varying width of the shaded portion indicating the tonnage of oil of vitriol produced reflects for the most part, so far as the period 1889 to 1917 is concerned, the enormous growth of the petroleum-refining industry. Its decline since that time represents displacement by oleum or fuming acid, the production of which is shown by the increasing vertical distance between the two top lines in the chart. Note that the production of oleum did not expand with any degree of rapidity until after the World War began to make the nations of Europe, and ultimately our own country, insatiable customers for high explosives such as TNT (trinitrotoluol). After the war there took place a rapid growth in the manufacture of coal-tar dyestuffs, notably indigo, the production of oleum consequently nearly doubling between 1921 and 1923. It virtually doubled again between 1927 and 1929, a phenomenon due in part to startling improvements in methods of manufacture and in part to the increased consumption of nitrocellulose finishes and lacquers by a flourishing automobile industry.

A glance at Table 3 shows the shifts in the amounts of the various strengths used even more emphatically than the chart. Note first that the maximum tonnage of chamber acid and oil of vitriol occurred in 1919 and 1917, respectively. By 1929, despite a more than 40 per cent increase in the total tonnage produced of all strengths, chamber-acid tonnage had gone down a third (from 2,750,000 tons in 1919 to 1,879,000 tons in 1929) and oil of vitriol tonnage more than

TABLE 3

Production of Sulfuric Acid, by Strengths, 1889–1929*

Year	50° Bé. Acid Quantity (*Tons*)	50° Bé. Acid Value	50° Bé. Acid Average Value per Ton	60° Bé. Acid Quantity (*Tons*)	60° Bé. Acid Value	60° Bé. Acid Average Value per Ton	66° Bé. Acid Quantity (*Tons*)	66° Bé. Acid Value	66° Bé. Acid Average Value per Ton	Oleum and Other Acids Quantity (*Tons*)	Oleum and Other Acids Value	Oleum and Other Acids Average Value per Ton
1889	504,932	$ 4,307,067	$ 8.53	10,190	$ 122,940	$12.06	177,267	$ 3,249,466	$18.33			
1899	953,439	7,965,832	8.35	17,012	246,284	14.48	382,279	6,035,069	15.79			
1904	1,169,141	8,314,646	7.11	48,688	581,523	11.94	411,165	5,917,699	14.39	13,268	$ 361,018	$27.20
1909	1,624,178	8,494,451	5.23	186,900	1,089,350	5.83	558,078	6,719,259	12.04	31,349	476,135	15.18
1911	1,026,896	5,447,958	5.31	421,165	2,624,042	6.23	751,541	9,176,297	12.21	10,728	121,575	11.33
1912	1,047,483	5,378,411	5.13	451,172	2,727,764	6.05	774,772	9,360,630	12.08	66,166	871,214	13.17
1913	1,643,318	9,212,917	5.61	509,929	3,202,528	6.28	797,104	9,282,422	11.65	63,158	986,659	15.62
1914	1,628,402	9,712,056	5.96	551,955	3,376,242	6.12	916,192	10,509,491	11.47	65,890	882,158	13.39
1915	1,518,271	10,681,246	7.04	657,076	4,976,453	7.57	1,019,024	14,211,381	13.95	189,795	2,787,971	14.69
1916	1,829,471	17,484,273	9.56	1,119,753	12,362,884	11.04	1,580,100	32,860,212	20.80	443,332	10,806,757	24.38
1917	2,199,224	30,552,396	13.89	1,350,416	15,129,343	11.20	1,359,739	25,832,797	18.99	759,039	16,034,645	21.12
1919	2,750,112	31,241,272	11.36	1,020,052	10,200,520	10.00	834,195	15,941,466	19.11	151,804	3,828,497	25.22
1920	2,165,069	23,081,880	10.66	1,334,615	13,495,579	10.10	1,153,976	22,714,947	19.68	502,970	10,624,049	21.12
1921	1,321,581	14,312,722	10.83	944,422	9,548,106	10.11	593,575	10,630,928	17.91	610,500	11,636,130	19.06
1923	1,564,066	12,889,320	8.24	1,512,816	12,421,730	8.21	800,631	11,913,000	14.88	1,164,889	18,986,102	16.30
1925	2,154,724	16,184,000	7.51	1,203,048	9,431,500	7.84	966,429	12,659,840	13.10	1,161,370	17,855,600	15.37
1927	2,565,474	20,160,900	7.86	1,006,691	8,758,290	8.70	924,356	13,629,000	14.74	1,305,772	19,851,000	15.20
1929	1,879,148	14,712,570	7.83	1,527,387	12,826,800	8.40	353,567	4,961,000	14.03	2,588,650	34,298,950	13.25

* Data for the years 1889 to 1917 and for 1920 were taken from the respective issues of United States Geological Survey, *Mineral Resources of the United States*, articles on "Sulphur." Data for 1919 and for 1921 to 1929 were taken from the United States Bureau of the Census, *Census of Manufactures*, section on "Chemicals." Total production figures were obtained by adding the quantities reported sold to those reported consumed where made. Total value is computed by assuming that all of the acid of a given grade would sell at the same price as that which was actually marketed. Data since 1929 not given according to strengths.

three-fourths (from 1,360,000 tons in 1917 to 354,000 tons in 1929). The production of tower acid, while it tripled every five years from 1899 to 1914, has since 1917 remained fairly stable, fluctuating with conditions in the nonferrous-metal industries. The output of oleum, on the other hand, has increased by leaps and bounds, in 1929 nearly equaling in tonnage (on a 50° Bé. basis) the total production of the other three strengths put together.

Comparing the relative aggregate values of the four kinds of sulfuric acid, notice that in 1909 the value of the chamber acid produced constituted slightly more than half the value of all acids, whereas in 1929 this predominance was enjoyed by oleum. The table below shows the details.

TABLE 4

PERCENTAGE OF AGGREGATE VALUE OF ALL STRENGTHS, 1909–1929*

Year	Chamber Acid	Tower Acid	Oil of Vitriol	Oleum
1909	50	6.5	40	3.5
1919	52	17.0	14	17.0
1929	22	19.0	8	51.0

* Computed from data in Table 3.

PRICES OF THE VARIOUS STRENGTHS

Giving brief attention to Figure 4, note that the curve at the top showing the average value per ton of oleum declines rapidly from 1904 to 1911, during which time a new process for making it[5] was rapidly introduced. It rises precipitously during the war years, when it commanded a scarcity price in the manufacture of high-explosive shell-filler, but declines steadily thereafter. The broken line representing the unit value of 66° Bé. acid similarly shows a steady decline from 1890 to 1914 and thereafter follows closely the course of

[5] The contact process, see chapter v, pp. 52–55.

oleum except in 1927 and 1929. A similar discrepancy appears when the two lower lines are compared, the unit value of the less concentrated 50° Bé. acid not staying below that of the 60° Bé. acid during the period from 1917 to 1923.

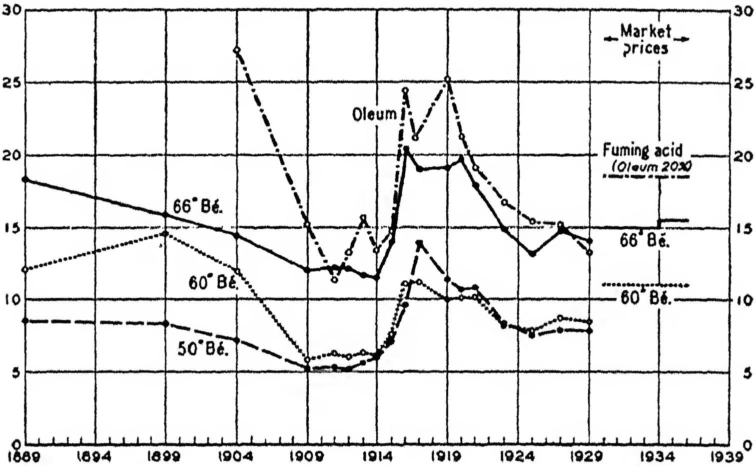


FIG. 4.—Average value per ton of sulfuric acid of various strengths, 1889–1936 (dollars per ton). For sources of data, see Table 3. Market prices of fuming acid (oleum 20%), tank cars, works, and 66° Bé. acid, tank cars, works, were taken from the files of *Chemical Industries*, formerly *Chemical Markets*. That of 60° Bé. acid, tank cars, works, is taken from the files of *Chemical and Metallurgical Engineering*.

The explanation of these discrepancies (detailed proof will be postponed until later[6]) lies first of all in the circumstance that in a given market there may be a demand for only one of the grades. The extraordinary rise in unit value of 50° Bé. acid during the war period was the result of such a demand in the South for phosphate fertilizers, coupled with the fact that sulfuric acid is too cheap and too difficult to ship to bear the cost of transport over long distances. The existence of local areas of imperfect competition is similarly indicated by the considerable narrowing of the spread between

[6] See chapter viii, pp. 145–47.

60° Bé. acid and 50° Bé. acid in 1909 and the failure of 60° Bé. acid to rise after 1916. As will become evident later,[7] 60° Bé. acid is the strength in which sulfuric acid first appears as a by-product in the operations of certain zinc and copper smelters. These first began to produce it in large quantities about 1906. Under the stimulus of the World War they expanded their production of the metals beyond the power of the local sulfuric acid market without a concession in price to absorb the acid by-product — a typical joint-cost phenomenon.

In the second place, the fact must be continually borne in mind that the curves on Figure 4 have in some respects an artificial quality about them in that they show for the years indicated by the circles and dots the average values per ton over the whole of the United States and not actual prices in a particular market. Notice in the segment of Figure 4 marked off in the lower right-hand corner that the course of actual prices even during the depression has been remarkably stable, in fact inflexible. Stability for considerable periods of time is characteristic of the behavior of sulfuric acid prices. Thus 60° Bé. acid was quoted at $0.85 to $1.00 per 100 pounds, spot, New York, and 66° Bé. acid at $0.01 to $0.011 per pound, spot, New York, from January 1912 to August 1915 and June 1915, respectively.[8] And at a given works the weaker strengths are obviously never quoted at higher figures than the stronger. In short, the variation and the discrepancy between the averages result from the wide variation in prices and in consumption of the same strength in different markets and from the process of averaging.

[7] See chapter vii, pp. 112, 115.

[8] See United States Tariff Commission, *Tariff Information Survey* FL 1 *Acids Exempt from Duty* (Washington, D.C., 1921), p. 36; and *Summary of Tariff Information, 1929,* "Schedule 15, Free List" (Washington, D.C., 1929), p. 2169.

WORLD PRODUCTION

A comparison of the growth of the sulfuric acid industry in the United States with those abroad serves to show its progress in striking fashion. Insignificant when compared with English production in 1865, and still less than one-third the size of England's output in 1880, the production of sulfuric acid in the United States substantially equaled that of Germany in 1900, doubled that of Great Britain shortly before the World War, and became nearly three times as large as any other in the world in the prosperous era that ended in 1929. From less than one-sixth of world production in 1880 the output of sulfuric acid in the United States became two-fifths of it in 1925.

Table 5 pictures the situation in a nutshell. While the figures, though based as far as possible on census returns, are at best approximate, they clearly show the early predominance of Great Britain and the later decline which accompanied the displacement of the Leblanc soda industry there by the Solvay ammonia-soda industry in the United States, Belgium, England, and Germany. They also show the extraordinarily rapid growth of the sulfuric acid industry in Germany during the period from 1880 to 1900, a result of the swift development of the coal-tar dyestuffs industry there. Note the substantial shift in position of France and Germany after the World War. It is significant that although world production in 1925 was about 25 per cent greater than in the years 1913–1914, the output of Germany and Great Britain fell off roughly a third while that of the United States nearly doubled.

Thus today the sulfuric acid industry in the United States is far larger than that of any other country in the world, furnishing unmistakable evidence of the vitality and varied development of our chemical enterprise. Because its products are so cheap and so widely used, the sulfuric acid indus-

TABLE 5

WORLD PRODUCTION OF SULFURIC ACID, 1867–1914

(Tons of Monohydrate or 100% Acid)*

Country	1867	1878	1900	1910	1913–1914	1925
Great Britain	155,000	600,000	1,000,000	1,000,000	1,082,000	848,000
United States	40,000	180,000	940,000	1,200,000	2,250,000	4,257,000
Germany	75,000	112,000	950,000	1,250,000	1,686,000	1,125,000
France	125,000	200,000	500,000	500,000	900,000	1,500,000
Italy	.....[a]	.....[a]	200,000	.....[a]	600,000	770,000
Belgium	20,000	30,000	165,000	.....[a]	420,000	462,000
Netherlands	.....[a]	.....[a]	.....[a]	.....[a]	320,000	350,000
Spain	.....[a]	.....[a]	.....[a]	.....[a]	60,000	320,000
Japan	.....[a]	.....[a]	50,000	.....[a]	70,000	210,000
All others (Austria, Czechoslovakia, Denmark, Sweden, Australia, etc.)	85,000	165,000	425,000	1,050,000	558,000	721,000
World production	500,000†	300,000†	4,200,000†	5,000,000	7,946,000	10,563,000

* Figures for 1867, 1878, and 1900 (with the exception of those for the United States, "All others," and "World production") taken from Drösser, *op. cit.*, p. 7. Those for 1910 are taken from *Journal of the Society of Chemical Industry*, special Jubilee number, July 1931, an article of Professor Percy F. Frankland, "The Chemical Industries of Germany," p. 226. Those for 1913–1914 and 1925 are taken from *The Times Trade and Engineering Supplement* (London, November 26, 1927), Vol. XXI, No. 490, p. 7, which amplifies somewhat figures for the same years given on a 50° Bé. basis by Dr. C. Ungewitter, *Monographie über die Chemische Industrie* (Berlin, 1926), p. 21.

[a] Included in "All others."

† Approximately.

try can fairly be said to have played an indispensable part in making the chemical industries of the United States strong. It is the basic industry the strength of which has enabled the American chemical industry to compete vigorously in, if not to dominate, some of the most important chemical markets in the world.

V. Interprocess Competition

One of the striking differences between the chemical industry and industries relying on such physical manipulations as spinning, weaving, cutting, assembling, fitting, molding, or transporting is that in the latter, even though the machinery in the different plants may vary considerably in size, flexibility, and so forth, the process generally does not; it still remains cutting or spinning. In chemical industries the fact that chemical transformations take place opens the way for the development of competing processes which may or may not use the same raw materials, the same engineering operations, or the same apparatus and equipment. In usual instances these do not coincide.

The sulfuric acid industry furnishes an excellent case in point. Even from the very beginning there was one source of demand which could not be supplied by the chamber process acid. It had been discovered about 1750 that indigo when sulphonated would dye wool. But the sulfuric acid required was the fuming acid, or oleum. Now this, while of course readily obtainable from metallic sulfates, particularly copperas or alum, was made in the United States prior to the twentieth century only in laboratory amounts.

Industrially, fuming or Nordhausen acid was supplied even in Europe by a single manufacturing concern, founded by Starck at Nordhausen in Bohemia in 1778. Because of the cheapness of labor and the excellent quality and easy workability of the vitriol slates there, Starck's successors practically had a monopoly of its production during the next century. "In 1792 one hundredweight fuming oil of vitriol[1] cost in Bohemia fifty florins [say, $25.00], in 1873, 10

[1] G. Lunge, *The Manufacture of Sulphuric Acid and Alkali,* Vol. I, Part III, p. 1264.

florins [$5.00]. The production in 1832 was about 1,000 tons, in 1846, 3,000 tons, in 1884, 4,350 tons."

In the year 1900, this producer was compelled to abandon operations: A new process had won the field, one which used not vitriol stone as a raw material, but sulfur, and produced fuming acid of any desired strength in large quantities. It required no lead chambers, Glover towers, or Gay-Lussac towers, but did require a catalytic mass in the presence of which, or in "contact" with which, the reactions of the gases (sulfur dioxide and oxygen) necessary to produce sulfuric acid are greatly accelerated. The catalyte or catalytic agent itself, while it may enter into the reactions, is present at the end of the series in substantially the same form and amount in which it entered. It was formerly thought to change the rate of reaction by its mere presence, i.e., by mere contact; hence the name, contact process.

SCIENTIFIC HISTORY OF THE CONTACT PROCESS

The story of the contact process is a saga of patient, detailed scientific research. As early as the year 1817, the English chemist, Sir Humphrey Davy, noted that heated platinum, introduced into a mixture of such gases as air and hydrogen, carbon monoxide, ethylene, or cyanogen, caused the gaseous mixtures to burn. In 1823 Doebereiner showed the catalytic action of finely divided platinum on alcohol vapor, and the like. In 1830 the French chemists Dulong, Thenard, and Dumas found that other substances possessed similar properties. In 1831 Peregrine Phillips of Bristol, England, secured a patent for the process of forming sulfur trioxide from air and sulfur dioxide by drawing them in proper proportions through an ignited tube of platina. This patent, the very wording of which constitutes a fairly good description of the process today, remained unnoticed except by men of science in countries outside of England.

Jullian, in 1846, found that platinized asbestos served exceptionally well as a catalyst. Wöhler and Mahla, in 1852, discovered the serviceability of oxides of iron, copper, and chromium. Others discovered other interesting scientific facts about the reaction, but none of the scientists, after solving the scientific problems which provoked their experiments, seemed to have the interest, the resources, or the stimulus to undertake the further routine of detailed analysis necessary to make their laboratory accomplishment a steady, large-scale, factory operation.[2]

There were other reasons no less important, however. In a day when practically the only grades of sulfuric acid demanded were those of weak strengths, industrial inventors naturally directed their energies toward replacing the lead-chamber process, which at the time required so much expensive niter and such an expensive plant. Seeking, thus, to make dilute sulfuric acid, they took no pains to exclude moisture in their experiments. Indeed, sometimes they introduced water or steam on purpose. Precisely this fact caused the catalytic action to be very slow and imperfect. Moreover, none realized that minute quantities of flue dust and impurities would tend to "poison" the contact mass, that is, make it inactive. Furthermore, chemical-engineering research and the iron and steel equipment then to be had were not yet advanced to the point that they could meet with readiness the problems of apparatus and equipment which always arise when laboratory test-tube reactions are reproduced on a large scale in plant operations.

To close the gap between scientific research and industrial application required the pressure of demand. Such pressure came into existence in intense form with the synthesis of alizarin by Graebe and Liebermann in 1868. The industry

[2] For a full account of the scientific researches during the period 1831 to 1875, see G. Lunge, *op. cit.*, Vol. I, Part III, pp. 1275–1300.

at Nordhausen being unable to expand its production with adequate rapidity, the price of fuming acid rose more than 50 per cent in the years from 1872 to 1876, being quoted then at 1 mark per kilogram, or, roughly, $220 a short ton.[3] Since the contact process gives the sulfur trioxide direct, a considerable prize awaited the first inventor to make its industrial manufacture feasible.

At this juncture Clemens Winkler published an epoch-making paper.[4] It "acted upon the industrial chemical world like a sorcerer's wand upon pent-up spirits."[5] Curiously, however, while stimulating no small amount of renewed effort to solve the problem, Winkler's paper delayed considerably a commercial realization of the process. He stated that sulfur dioxide and oxygen had to be united in the exact stoichiometric proportions of the chemical formula, all excess of oxygen and inert gas or nitrogen content of the air fed into the burners being removed as injurious diluents. The obvious fallacy of such a contention should have been seen by those who were aware of the law of mass action formulated by the Norwegian chemists Guldberg and Waage, in 1867. For, according to this law, an excess of oxygen in the instance under discussion would hasten and make more complete the using up of the sulfur dioxide—two highly desirable results. Probably every professor of chemistry mentioned Winkler's paper in his lectures from 1875 on, yet, as Lunge asks, "Why was Winkler's reasoning never protested against, as contrary to the above law, until Knietsch did so in 1901?"[6] The authority of Winkler apparently kept the two ideas in watertight compartments for twenty-five years.

Winkler's paper also contributed to misdirecting the ener-

[3] See the tables of prices of chemicals given by J. W. Kockerscheidt, *Über die Preisbewegung Chemischer Produkte* (Jena, 1905).

[4] In the *Dinglers Polytechnisches Journal,* CCXVIII (1875), 128.

[5] G. Lunge, *op. cit.,* Vol. I, Part III, p. 1289.

[6] *Ibid.,* p. 1291.

gies of some of the industrialists of the time. To get the pure oxygen and sulfur dioxide alleged to be required, Winkler stated that they could be secured by decomposing sulfuric acid. Several firms constructed plants for the purpose of carrying out this utterly impracticable process, among them the Badische Analin und Sodafabrik at Ludwigshafen am Rhein, the Farbwerke vormals Meister, Lucius und Brüning zu Höchst, and the Verein Chemischer Fabriken Mannheim. All of these companies were thought to be following Winkler's process, until suddenly, almost in the same month in 1898, each took out a patent for making sulfuric acid by a contact process.

So many details of the process were simultaneously and independently discovered by Winkler at Freiburg, by Knietsch at Ludwigshafen, by Clemm and Hasenbach at Mannheim, and by Herreshoff and Ferguson in the United States, to mention only a few, that no attempt will be made to assess the exact portion that may have been contributed by each. But the lion's share of the honor seems to be deserved by Dr. Knietsch and by the German businessmen who for nearly twenty years kept spending large amounts for research in order to make the process a practical one.

During the course of this long, patient, and systematic program of experimentation German industry made use of the most advanced and complicated mathematical tools known to chemical science, employing scores of chemists to observe numberless reactions in order to ferret out the one elusive balance of thermodynamical, chemical, and physical conditions which was required to make the process economically feasible.[7] The authors of a standard American treatise on the manufacture of sulfuric acid state:

[7] For a full account, consult Knietsch's address on the subject of the contact process to the German Chemical Society, *Berichte der deutschen Chemischen Gesellschaft* (1901), pp. 4609 ff. For other accounts showing graphically the

It remained for a nation of real scientists to discover and develop the contact process. Nowhere in the field of industrial chemistry can the chemical engineer see so clearly the result of systematic, painstaking research, experiment and accurate interpretation of observation.[8]

Only the most important new discoveries concerning the contact process require mention. In the first place, Winkler was definitely proved to be in error, an excess of oxygen aiding rather than retarding action. Furthermore, the poisoning of the catalyst was found to be due to the presence of excessively small quantities of impurities such as arsenic, flue dust, sulfuric acid vapors, or mercury compounds. Therefore, towers in which the gases are scrubbed with sulfuric acid and filtered through layers of pulverized coke, slag, or asbestos wool were devised. Moreover, to avoid formation of colloidal mist, a slow cooling of the gas was found absolutely essential. Again it was established that platinized asbestos worked best as a catalyst when the gases were heated to a temperature of 450° C. The formation of the sulfur trioxide being an exothermic reaction, how keep the contact mass and apparatus from overheating? The answer to the problem consisted in devising a heat exchanger which at the same time pre-heated the gases and cooled the converter.

Thus, though there are more than a half dozen important modifications of the contact process in operation and innumerable variations in details of equipment, a contact acid plant consists fundamentally of four parts: the sulfur burners, in essence long, horizontal cylinders; the gas purification system, comprising the heat exchangers or air coolers and the scrubbers for removing the impurities (not necessary with

computations involved, see Lunge, *op. cit.*, Vol. I, Part III, pp. 1327–57, and J. R. Partington, *The Alkali Industry* (2d ed., van Nostrand, New York, 1925), pp. 34–49.

[8] Philip de Wolf and E. L. Larison, *American Sulfuric Acid Practice* (McGraw-Hill, New York, 1921), p. 5.

vanadium catalysts); the converters, where the gases are passed through finely divided masses of platinized asbestos, vanadium salts, iron oxide, or whatever serves as "contact" substance; and the absorbers, in which the sulfur trioxide or anhydride is absorbed in highly concentrated (98 per cent) sulfuric acid. The typical product is oleum, although, of course, sulfuric acid of weaker strength can readily be produced by adding water. The flow sheet below indicates the typical arrangement:

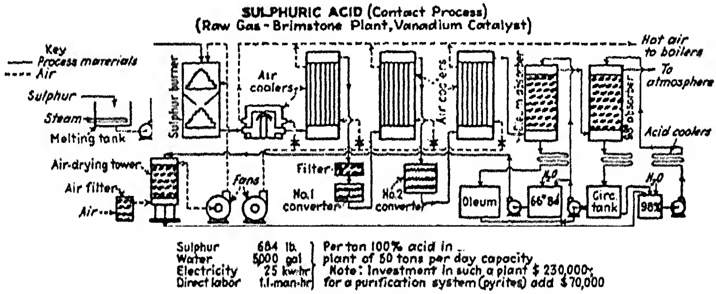


FIG. 5.—Flow sheet of sulfuric acid manufacture. From *Chemical and Metallurgical Engineering, Flow Sheets of Process Industries* (McGraw-Hill, New York, 1936), p. 48.

CONTACT PROCESS GAINS FOOTHOLD

In 1900 the sulfuric acid manufacturers of the world were all agog concerning what this new process might signify. Much was hoped for, and much feared. Winkler expressed the enthusiasm of many fellow technologists when he wrote that "in no distant time lead chambers will be dispensed with."[9] As it proved in the United States, however, the two processes became complementary. The field has been divided between them.

At first there was a considerable scramble to put up contact

[9] C. E. Munroe and T. M. Chatard, "Chemicals," *Twelfth Census of the United States, 1900*, Vol. X (*Manufactures*), Part IV, p. 533.

acid plants, a variety of processes being tried, among which the most important were the Höchst, Grillo-Schroeder, Mannheim, Freiberg, Tentelew, and Rabe processes. With one possible exception[10] American companies made no successful attempt to develop their own processes. As a general rule "American manufacturers, due to their lack of appreciation of the results of organized research and experiment, refused to finance any work along these lines, and followed the usual course of importing the developed process and trained men for installations in this country."[11]

There were only a few installations of the original Badische process. While it had been demonstrated at a plant in New Jersey in 1898, apparently the royalties demanded were excessive.[12] Some twelve American sulfuric acid producers accordingly combined under the leadership of Dr. Nichols for reasons which may have included that of united use of the Herreshoff process developed in his company. The new combination, the General Chemical Company, was soon involved in litigation with the Badische concern, as a result of which it "acquired the rights in the United States but its plants, built prior to the litigation, were not altered substantially after the settlement."[13]

The first and "most widely used platinum contact process system in the United States has been the Schroeder-Grillo,"[14] the patents to which were obtained by August Hecksher of the New Jersey Zinc Company in 1899. A subsidiary concern manufactured in 1901 the first contact acid produced in the

[10] The possible exception is the process developed by Herreshoff, chief chemist at the Laurel Hill works of The Nichols Chemical Company.

[11] De Wolf and Larison, *op. cit.*, p. 5.

[12] Williams Haynes, *Chemical Economics* (van Nostrand, New York, 1933), pp. 177–78.

[13] William M. Grosvenor, "Sulphuric Acid," in Allen Rogers (ed.), *Manual of Industrial Chemistry* (2 vols., van Nostrand, New York, 1931), Vol. I, chapter iv, p. 164.

[14] *Ibid.*, p. 168.

United States at Mineral Point, Wisconsin.[15] Soon several other companies, notably E. I. du Pont de Nemours, Inc., and Harrison Brothers, built plants using the same process.

Another process which quickly found considerable adoption was the Mannheim process, which uses an iron-oxide catalyst as well as platinum. The first Mannheim plant was erected in 1903 by the Schoelkopf, Hartford and Hanna Company of Buffalo, New York. Within two years a total capacity of over 50,000 tons per year had been installed.[16]

By and large the manufacture of contact acid remained on an imitative basis until after the World War. About 1920, however, the industry in the United States began to make independent progress, especially through the development of vanadium catalysts. Their use had been suggested in Germany as early as 1895 by Johann Walter.[17] Their freedom from "poisoning" compared with platinum had been shown by Küster in 1904. Numerous patents had been taken out abroad before the war, using iron- and silver-vanadium compounds, vanadic acid, and the like.[18] But it was an American chemist, A. O. Jaeger, who solved the problem. Early in the 'twenties he developed in the laboratories of the Monsanto Chemical Company a series of complex vanadium silicates that were not only cheap relative to platinum but possessed high catalytic activity immune to "poisoning" by arsenic or hydrochloric acid. Thus most of the costly purification apparatus can be dispensed with, the raw gas from the sulfur burners being processed with an average conversion efficiency of 95 to 98 per cent. In addition, Mr. Jaeger developed an

[15] Lunge, *op. cit.*, Vol. I, Part III, p. 1419.

[16] C. E. Munroe, "Chemicals and Allied Products," *Census Bulletin No. 92* (Department of Commerce and Labor, Washington, D.C., 1908), p. 22.

[17] In *Journal für praktische Chemie N.S.*, LI, 108.

[18] For a list of these patents, see L. F. Nickell, "New Vanadium Catalyst for Sulphuric Acid," *Chemical and Metallurgical Engineering* (March 1928), p. 153.

automatic temperature-control converter permitting a great saving in labor cost and ground space. As a result the tables have been completely turned. The United States is now building contact acid plants for Europe, the Chemical Construction Corporation (a subsidiary of the American Cyanamid and Chemical Corporation) specializing in putting up, among other types of sulfuric acid plants, "Chemico" contact acid units here and abroad. These, among lesser improvements (such as the use of silica gel as a carrier for platinum and the employment of the Heckenbleikner spray sulfur furnace, which burns sulfur as oil is burned in a household oil furnace), "have resulted in a great increase in the number of contact acid plants in the United States since 1927 and have almost revolutionized the American sulphuric-acid industry since they have so simplified the contact acid process as to permit the manufacture of 66° Bé. acid by dilution of contact plant acid more cheaply than by concentration of chamber acid."[19]

IMPROVEMENTS IN THE CHAMBER PROCESS

The competition of the contact process exerted pressure upon the old-established and conservative chamber acid industry to lower its costs, which it proceeded to do in three ways: by endeavoring to eliminate hand labor; by reducing plant investment; and by economizing on raw materials. Most of the improvements were individually small, varied widely in their application from plant to plant, frequently consisted of short-cuts or "dodges" jealously guarded as trade secrets or regarded as tricks of the trade, and rarely involved a familiarity with advanced scientific knowledge. In fact, an English chemist has said:

great technical improvements may often be effected by the wise application of apparently quite elementary scientific principles, and of

[19] Allen Rogers (ed.), *Manual of Industrial Chemistry*, I, 163.

empirical methods; and the evolution, especially in recent years, of the chamber process, of which the chemical mechanism is even yet not entirely elucidated, affords an interesting illustration of such developments.[20]

The chief way in which the advent of the contact process helped to bring about a reduction in labor costs was by hurrying the adoption of mechanical burners for "fines" pyrites. The old lump-burner ovens, the narrow staggered shelf burners, and the broad shelf burners rabbled by hand all had the serious disadvantage of requiring laborers with a skill equal to that of locomotive firemen in controlling the charge and draft. In addition, the opening and closing of the doors involved considerable losses both of heat and of sulfur dioxide, with attendant danger of poisoning by fumes containing arsenic, hydrochloric acid, and so forth.

Early in the 'seventies the McDougall Brothers in England and Perret in France began to develop a circular or rotary burner which was improved upon frequently by these inventors, by Mackenzie, Frasch, Herreshoff, and others. But the tendency to eliminate hand labor at the burners was especially strong in the United States,[21] so that in 1901, despite the fact that no more than a fourth of the sulfuric acid of the world was produced here, the United States had the most improved mechanical burners in ten plants while in Europe they were used in but fourteen.[22] This tendency continued throughout the period.

At present, as is shown by the extract from a current advertisement, on opposite page, mechanical burners are automatically operating devices of considerable complexity.

[20] S. I. Levy, *An Introduction to Industrial Chemistry* (McGraw-Hill, New York, 1926), p. 200.

[21] Drösser, *op. cit.*, p. 49.

[22] United States Tariff Board, *Chemicals, Oils, and Paints. Glossary on Schedule A* (Washington, D.C., 1912), p. 14. See also "Sulphuric Acid," *The Encyclopaedia Britannica* (11th ed., University Press, Cambridge, 1911), p. 66.

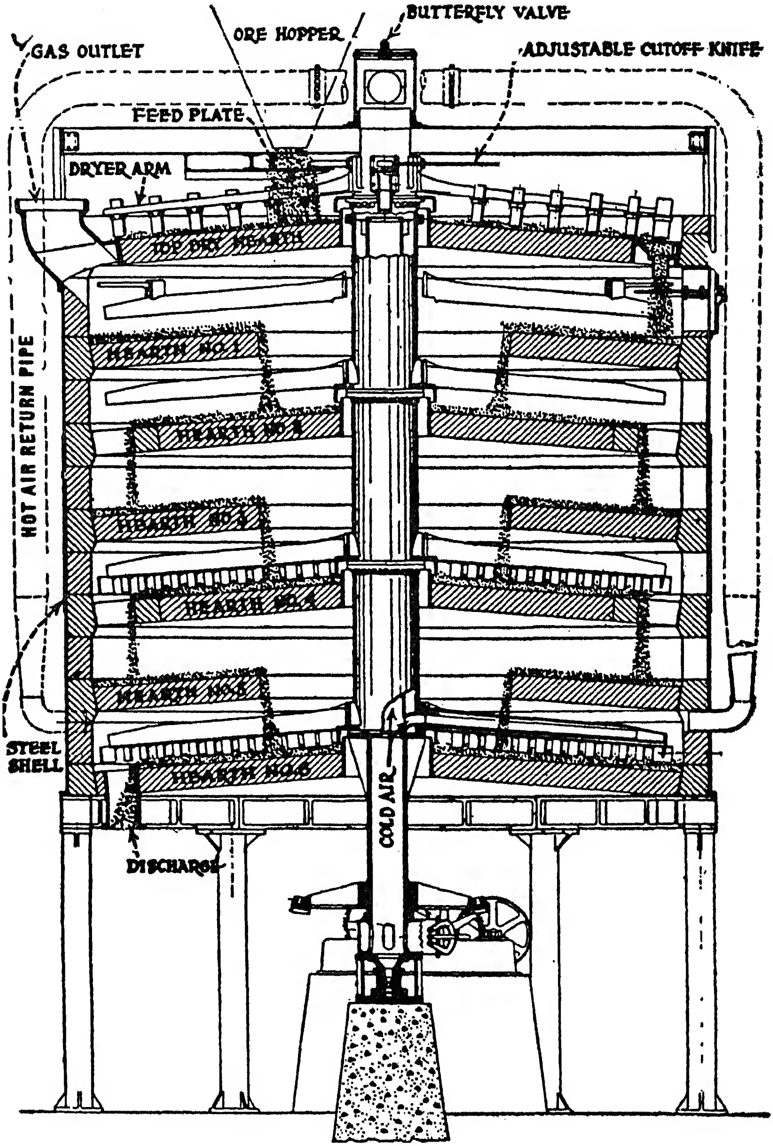


FIG. 6.—A modern pyrites furnace. From an advertisement in *Chemical Markets* (at present called *Chemical Industries*).

The following patented features of the Nichols-Herreshoff furnace for roasting of ores, for metallurgical purposes and manufacture of acids, for calcining and drying and many special purposes—make it the leading equipment for low cost operation and production:

1. Efficient and complete air-cooling of all exposed parts
2. Return of heated cooling air directly to furnace on any hearth for combustion purposes
3. Inclined arms—parallel to hearth floor—thereby reducing weight of ore on hearths
4. Quick removable rabble arms from furnace door without cooling furnace
5. Greater number of hearths for the development of more drops from hearth to hearth with greater exposure to oxidation
6. Large gas port areas within furnace for purpose of reducing gas velocities with lower dust loss
7. Rabble teeth removable at will—designed to allow quick passage through furnace or back rabbling so as to retain ore in furnace any time
8. Shaft step designed for reduced power and any speed regulation desired
9. Top drying hearth end sealed feeds

The efficiency of its air cooling system and other features is testified to by the fact that there have been over 950 Nichols-Herreshoff furnaces sold in the United States and Canada. These range from 2 ft. inside diameter to 22 ft. outside diameter, and from 1 hearth to 11 hearths, as demanded by the conditions involved. The Nichols-Herreshoff furnace can be adapted to many different processes. We invite your consultation on any roasting, calcining, or drying problem.

According to the advertisement, the use of mechanical burners in chamber acid manufacture is, of course, not only due to the competitive threat of contact acid but follows primarily from the fact that rates of wages are high. The nature of the business computations involved appears clearly from the following table:

TABLE 6

COMPARATIVE COSTS OF HAND AND MECHANICAL BURNERS*

Items of Expense	Amount Required: Herreshoff Burners	Amount Required: Shelf Burners	Unit Rate	Total Cost in Marks for 360 Two-Shift Days: Herreshoff Burners	Total Cost in Marks for 360 Two-Shift Days: Shelf Burners
Power		None	4 Pfennig per hour	1,728	None
Labor	2 men	4 men	3 marks a day	4,320	8,640
Amortization and interest	5 burners costing 60,000 marks	20 burners costing 32,000 marks	15%	9,000	4,800
Repairs, etc.				1,250	1,200
Total				16,298	14,640
Total if labor is paid at rate of 4 marks a day.				17,738	17,520
Total if labor is paid at rate of 5 marks a day.				19,178	20,200

* Adapted from Drösser, *op. cit.*, p. 50.

Many other devices have been utilized to get operating labor expense per unit of product down to optimum levels, consisting primarily of more equipment per unit of labor; mechanical devices such as acid lifts, fans, conveyor belts, and so on; automatic analysis to save labor expense of chemists making routine analytical tests at regular intervals; automatic operation of the equipment from one central room containing the recording and controlling pyrometers, thermometers, pressure gauges, and so forth; and automatic and continuous flow of the process.

In the second place, there were a whole series of improvements tending to reduce the amount of chamber space (and hence the amount of investment) required to produce a ton of sulfuric acid. In technical computations the number of cubic feet of chamber space is computed per pound/day of sulfur burned. Plants that in 1900 had not yet put in Glover and Gay-Lussac towers required 30 cubic feet as op-

posed to 20 cubic feet for those that had. By enlarging the Gay-Lussac capacity, by scientific packing (with vitrified brick, for example, instead of alternate layers of quartz and coke), and by rearrangement of the towers, plants were made to operate on 15 cubic feet of chamber space. By improved construction of towers (using acid-proof cement and brick), by the use of fans to ensure a thorough mixture of the gases and uniformity of operations regardless of atmospheric conditions, by rearrangement of intermediate towers, by putting in intensifiers (e.g., Hoffmann's), and devices such as Meyer's tangential system, Lunge's plate tower, and Gilchrist's column,[23] sulfuric acid producers were achieving an efficiency of 10 to 12 cubic feet.[24] Recently, with the aid of such improvements as Mills-Packard water-cooled chambers, Gaillard turbo-dispensers, and Schmiedel roller-boxes, the total chamber space required per pound/day has been reduced to as low as 6 cubic feet[25] in the United States and 4 cubic feet in England.[26] A veteran American producer estimated before the advent of these latest improvements that in the last thirty years in his experience "better construction and improved operating methods have resulted in a reduction in the item of repairs fully 20 cents per ton. The complete capital cost of a sulphuric acid plant today figures at least 20 per cent less, assuming identical cost of materials."[27]

[23] F. J. Falding in *Berichte Internationaler Kongress für Augewandte Chemie* (I, 768) reports that of 36 chamber plants which were completed or under construction in the United States in the period from 1900 to 1903 seven of the largest put in Gilchrist columns, others put in Hoffmann intensifiers, and so forth.

[24] See anonymous item (the report of a speech probably made by W. H. Nichols, president of the General Chemical Company) entitled "Sulphuric Acid by the Contact Process," *Electrochemical Industry* (now *Chemical and Metallurgical Engineering*) (September 1904), II, 349.

[25] Andrew M. Fairlee, "Sulphuric Acid Enjoyed Best Year since the War," *Chemical and Metallurgical Engineering* (January 1929), XXXVI, 44.

[26] Allen Rogers, *op. cit.*, p. 144.

[27] P. J. Hoffmann, "Progress in Sulphuric Acid Manufacture," *Chemical and Metallurgical Engineering* (July 1926), XXXIII, 407.

The third set of improvements, those lowering the expenses for raw materials, are similarly legion in number. None require individual mention except the substitution of ammonia oxidation for "niter potting" (or other device) as a source of nitrous oxides. Instead of the traditional batch process of putting niter pots in the flue carrying the burner gases to the Glover tower and charging them periodically with Chile saltpeter and Glover tower acid—a process involving irregular flow of the nitrous oxides, breakage of pots, and formation of undesirable by-product "niter coke" and hydrochloric acid gas—the majority of leading American plants since 1927 have adopted the continuous process whereby ammonia gas and air are passed through a platinum gauge screen, the ammonia being oxidized to nitrous oxide. Even if the nitrogen in ammonia were not purchasable at a cheaper unit price than the nitrogen in Chile nitrate (which it now is),[28] the increased continuity of the process and the avoidance of losses due to breakage, by-products, and consumption of Glover tower acid effect a considerable reduction in net cost.

While many plants have not yet installed an ammonia oxidation unit, all produce chamber acid with less consumption of raw materials than they did thirty years ago. It has recently been authoritatively estimated that

> the yield has been increased from an average of 4.05 to 4.85 [pounds of 50° Bé. acid per pound of sulfur burned], nitre consumption has been decreased from an average of 4.75 per cent to 2.50 per cent and coal consumption reduced [partly as a result of using atomized water spray instead of steam] from 200 lb. to 50 lb. per ton 50 deg. acid produced.[29]

[28] S. F. Spangler, "Ammonia Oxidation Replaces Niter for Chamber Acid Plants," *Chemical and Metallurgical Engineering* (June 1928), XXXV, 344, estimates ammonia at 6 to 7½ cents per pound ammonia content to be $20 to $13 per ton cheaper than the ammonia in Chile nitrate at $45 per ton.

[29] P. J. Hoffmann, *op. cit.*, p. 407. Munroe and Chatard (*op. cit.*, p. 531) summarize figures from 13 brimstone plants which produced from 446 to 321 parts of acid to 100 parts of brimstone, with an average of 391.

INTERPROCESS DIVISION OF THE MARKET

The relative success of the two processes in dividing the market for sulfuric acid is clearly shown in Figure 7. While

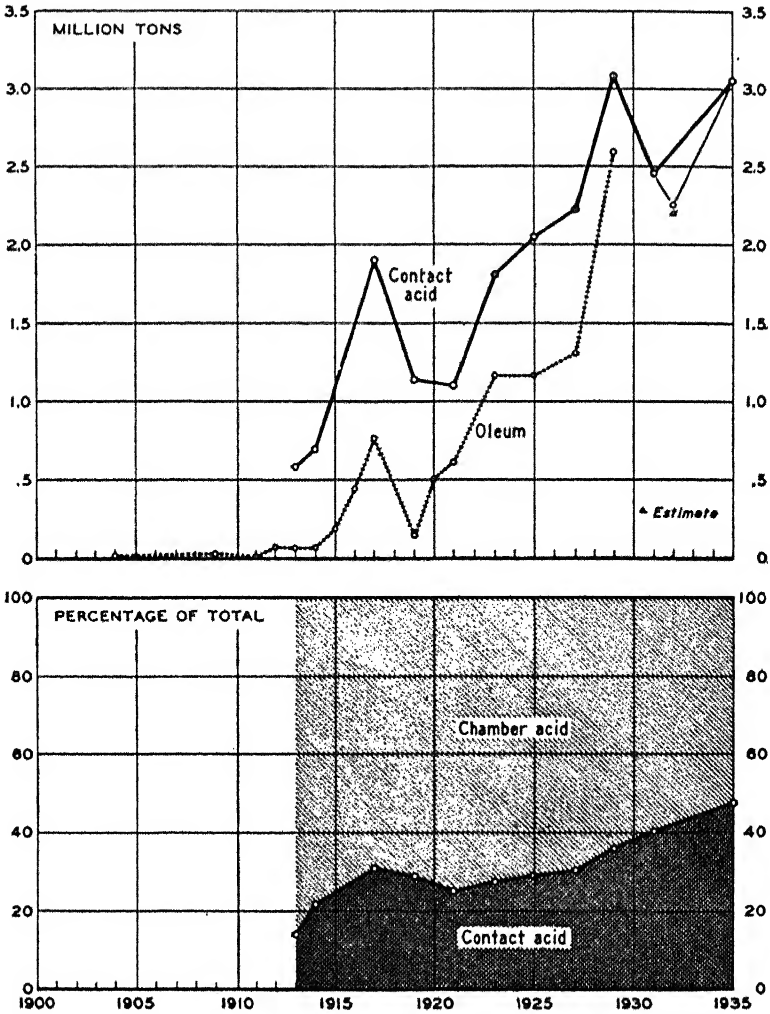


FIG. 7.—Growth of contact acid production, 1913 to 1935 (50° Bé. basis). For sources of data, see Table 7.

complete data are not available for the prewar period, the census figures on the production of oleum and acids of higher strengths indicate that despite considerable publicity in popular and technical discussions the contact process did not in reality provide formidable competition.

The reasons are twofold. In the first place, the advantages of the contact process were overestimated. To be sure, it does eliminate the expense of construction and maintenance of the entire chamber system, including the Gay-Lussac and Glover towers and the steam and niter plant. The plant also occupies less ground area and requires no expensive concentration equipment (e.g., of fused silica or platinum), inasmuch as it produces oleum free from lead and arsenic from which 66° Bé. acid and weaker strengths can be readily obtained merely by adding water. But before the war there was little demand for oleum and for pure sulfuric acid in general, inasmuch as more than half of the total production went into the manufacture of phosphate fertilizers, for which the impure chamber acid was just as good as any other at the same price.

Moreover, the disadvantages of the contact acid process were seriously underestimated. For at that time (prior to the development of vanadium catalysts) it not only required, as was noted above, a heavy investment in gas-purification equipment, scrubbers, platinum catalyst, and the like, but—and this was the crucial point—"a higher order of chemical engineering skill than has usually been deemed necessary for the operation of an acid plant."[30] Despite a host of improvements, the largest of American sulfuric acid concerns summarized twenty years of experience as late as 1920 as follows:

The working of the contact or catalytic process is much more

[30] Charles E. Munroe and Thomas M. Chatard, "Chemicals," *Twelfth Census of the United States, 1900,* Vol. X (*Manufactures*), Part IV, p. 536.

complicated and requires a very much higher order of chemical and manufacturing ability. Its operation has brought about standards of analytical work, the refinements of which were never dreamed of by any chemist previous to 1899. This change has brought about the application of machinery to a chemical plant—mechanical devices of every sort that prior to 1900 would have been regarded as unsuited to the chemical industry. Nowadays a chemical process plant looks much like a vast machine shop. The number of centrifugal pumps, automatic valves, pyrometers, etc., in use would astound any superintendent of ten or twelve years ago. Liquid, gaseous, and solid chemicals are now moved and controlled by machinery and tested by automatic devices.[31]

Even as late as 1925 standard treatises on industrial chemistry characterized the contact acid process as one in which "the operation is sensitive and delicate and involves the use of more refined machinery, so that a higher class of labor has to be employed."[32] Now chemists were relatively scarce in the United States in 1900. In the 127 sulfuric acid establishments in that year which reported to the Census Bureau there were employed only 28 chemists. Metallurgy and other fields were still too profitable. Thus the extension of the contact process was primarily limited by the difficulty in purifying the gases, which involved the necessity of bidding for relatively scarce chemical training.

The growth of the contact process, therefore, depended on the demand for pure acid or for acid of concentrated strengths, such as oil of vitriol and oleum. The older method was clearly at a disadvantage here, since a substantial cost of concentration had to be incurred to produce acid of such strengths. Thus it was not until after the World War had created a sudden demand for oleum and other concentrated strengths

[31] The General Chemical Company, *The General Chemical Company after Twenty Years, 1899–1919* (privately printed, New York, 1920), p. 46.

[32] Allen Rogers, *Manual of Industrial Chemistry* (3d ed., van Nostrand, New York, 1925), p. 190; and F. H. Thorp, *Outlines of Industrial Chemistry* (Macmillan, New York, 1923), p. 81.

for the making of TNT (trinitrotoluol) and other explosives that the contact acid industry prospered. In 1917 its output roughly quadrupled that of 1913. In 1918 it probably accounted for 29 per cent of the country's sulfuric acid production. It, of course, not only provided all the oleum but most of the production of 66° Bé. acid as well, only 41.6 per cent of the output of the latter in that year being made by heat concentration from the weaker chamber acid, while 58.4 per cent was obtained directly by the contact process.[33]

Turning again to Figure 7, note the expansion of both oleum and contact acid production during the war, its precipitate fall in 1919 due to the fact that the federal government was unloading war stocks of oleum, and the extraordinary growth since 1921. The figures at the top of the chart are even more striking in that they show the percentage of the entire market taken over by the contact process. They increase from 25 per cent in 1921 to 47 per cent in 1935. Not only has the chamber process completely lost the market for oil of vitriol but its hold is threatened even on the market for less concentrated strengths. The fact that Great Britain in 1926 produced only 11 per cent of her sulfuric acid by the contact process and Germany about 20 per cent[34] (a percentage which has remained the same for twenty years)[35] also indicates its relative competitive strength in the United States.

Further indicia of the vicissitudes of interprocess competition are given in Table 7, below. Notice the continuous increase in the number of establishments producing contact acid, particularly the 50 per cent jump between 1929 and 1935, and, even more striking, the considerable decline in

[33] H. L. Lewenberg, "Prices of Mineral Acids," *Price Bulletin No. 45* (United States War Industries Board, Washington, D.C., 1919), p. 6.

[34] *The Times Imperial and Foreign Trade and Engineering Supplement* (London, November 26, 1927), XXI, 6.

[35] In 1905 the figure was 19 per cent, according to G. Müller, *Die Chemische Industrie* (Teubner, Leipzig, 1909), p. 173.

TABLE 7

CONTACT VERSUS CHAMBER ACID, 1913–1936*

Year	Contact Percentage of Total	Number of Establishments			Number of Tons (50° Bé. Basis)					Weight of Platinum in Contact Mass (Troy oz.)
					Contact Acid		Chamber Acid			
		Contact	Chamber	Both	Total	Per Establishment	Total	Per Establishment	Both	
1913....	14[a]	..[b]	...[b]	..[b]	585,000	.....	2,950,000	.....	.....[b]	.....
1914....	22[a]	13	172	9	608,413	53,700	2,461,815	14,000	411,330	29,835
1917....	31[a]	..	...	..	1,900,000	.....	4,067,000[a]	.....	.....	.....
1919....	20[a]	24	185	7	1,141,418	48,000	3,757,887	20,000	653,270	38,485
1921....	25.2	..	...	..	1,102,567	.....	3,267,374	.....	.....	31,588
1923....	27.6	34	160	..	1,812,341	53,000	4,743,176	29,600	.....	36,650
1925....	29.2	37	153	13	2,050,530	55,400	4,953,582	32,000	.....	30,348
1927....	30.3	37	155	11	2,223,146	60,000	5,112,649	33,000	.....	31,462
1929....	36.2	42	141	13	3,076,240	73,000	5,414,874	38,000	.....	37,512
1931....	40.2	..[b]	..[b]	10	2,446,963	.....	3,638,279	.....	.....	.....
1933....	....	..	...	..	....	.....	....	.....	.....	.....
1934....	....	..	...	..	....	.....	....	.....	.....	.....
1935....	47.5	63	71	12	3,046,833	48,400	3,415,379	48,000	.....	.....

* Figures for 1913 and 1917 computed from data given for 100 per cent acid by the United States Tariff Commission, *Tariff Information Survey FL 1, Acids Exempt from Duty* (Washington, D.C., 1921), p. 31. Other figures are taken from the respective censuses of manufacture.

[a] Author's own computations or estimates.

[b] No data.

the number making chamber acid beginning during the prosperous 'twenties and culminating in the elimination of one-half of them between 1929 and 1935. In both branches of the industry the average establishment has been increasing its annual output: in the chamber process, from an average of 14,000 tons in 1914 to 38,000 tons in 1929; in the contact process, from 53,000 to 73,000 tons. Since 1929 a host of small contact acid units have been built and the smaller chamber units have been forced out of production, so that today the scale of operations does not materially differ. These figures indicate that it was the smaller plants, particularly those making phosphate fertilizers in the South, which clung to the chamber process. It must be remembered that technically the

contact unit is smaller. But those consuming large amounts of sulfuric acid have obtained their supply from contact plants to such an extent that today, and certainly in the near future, especially with the vanadium catalyst permitting the use of raw gases, the contact process not only is in the ascendency but definitely dominates interprocess competition.

COMPARATIVE COSTS

There is no item upon which data are more difficult to obtain and more likely to be incomparable than the item of costs. Plant accounts vary in setup, in definition and classification of items enumerated, in principles of charging off depreciation, in methods of crediting for by-products and other recoverable values, and in allocation of expenses for indirect labor, administration, research, taxes, and so forth. Even with a uniform system of operating reports, costs in the manufacture of sulfuric acid vary with the raw materials used, with the efficiency and skill of operation, with the level of output of the plant, with differences in the design and construction of the plant, not to mention local differences of transport cost, waste disposal, and the like.

The fact need not be emphasized, therefore, that the cost figures herewith presented are valuable solely as illustrations or samples. While they represent actual operations, they do so only in a particular plant at a particular time. They do not show the average, general, or most frequent relationships between cost items. They do give a point of reference above, below, and around which in a manner more or less haphazard the costs of the various sulfuric acid producers range themselves in space and time. All of the figures are averages representing the costs of items, not for the industry as a whole, but for a particular plant operating at a particular level of capacity during a particular period of time.

The relationship of contact process costs during the decade

following its invention as compared with those of chamber process costs appears clearly in the table below. Although

TABLE 8

COSTS IN 1902 OF CHAMBER PROCESS AND CONTACT PROCESS

(Dollars per Ton, 100% Acid Basis)*

Item	Chamber Process	Contact Process
Pyrites (50% Portuguese ore at $5.00 a ton)	$3.20	$3.20 (sulfur)
Chile saltpeter	0.52	....
Coal	0.47	$0.40 $0.93
Wages (mechanical ovens)	$0.41 $0.56	0.61 - 0.87
Repairs	0.30 - 0.35	0.30 - 0.47
Amortization, etc.	0.91 - 1.46	$1.67
Royalties		0.26
Total (to nearest ten cents).	$5.80 $6.60	$6.40 $7.30

* Adapted from Drösser, *op. cit.*, p. 133.

the precision of the figures is one of computation rather than actuality, they are sufficiently accurate to show that the contact process was the costlier mode of manufacture. The reasons are chiefly higher labor costs and higher amortization charges.

The totals in Table 8 must not, however, be taken to mean that the chamber process could produce a ton of real 100 per cent acid cheaper than the contact process. It could produce only the quantity of sulfuric acid going into such a ton more cheaply but, of course, in the form it emerges from the lead chambers, i.e., 50° Bé. acid. To make the stronger acids required an expensive process of concentration.

How expensive this operation may have been can be got at roughly from comparing again the curves on Figure 4, p. 42, above, showing the differential in average value between 66° Bé. acid and 50° Bé. acid. From Table 2, p. 36, notice that the stronger acid has about 50 per cent more acid

in it than the weaker. Multiplying the price of the weaker acid by 1½ yields the price of the stronger acid, were there no cost of concentration. Thus in 1889 the cost of the sulfuric acid as such in the 66° Bé. acid is 1½ times $8.53, or $12.79. Table 2 shows that its actual average price was $18.33. The difference, or $5.59, gives a clue to the cost of concentration. In 1904 this difference was $3.72; in 1909, $4.15; in 1914, $2.53; in 1923, $2.46; and in 1929, $2.30.

While the decline in the differential from 1889 to 1909 was in large part due to the decreasing cost of concentration, the unusually small difference since 1914 clearly shows the competition of the contact process. If and when, and in those areas in which, it disappears entirely, the chamber process is, of course, threatened with losing even the 50° Bé. acid market which has been its mainstay.

The contact process, which has had a monopoly of producing oleum since 1900, began competing vigorously for the oil of vitriol or 66° Bé. acid market soon thereafter. By 1905 it was on an equal footing, as is shown in Table 9 below, which presents some calculations, based on world

TABLE 9

COMPARATIVE COSTS OF SULFURIC ACID

(Marks per 100 kg.)*

Type of Sulfuric Acid (*Percentage*)	Made in Platinum Gold Still	Concentrated from Chamber Acid in Kessler Furnace	Made by Contact Process
93	2.67–2.83	2.57	2.35–2.79
97–98	3.21	....	2.56–2.93

* Adapted from Lunge, *op. cit.*, Vol. I, Part III, p. 1254.

conditions in 1905, made by two German chemists, Diedenführ and Luty. Notice that according to these computations the contact process was already capable of making the mono-

hydrate more cheaply than even the most efficient chamber acid-concentration process.

The expense of concentrating chamber acid, it should be remembered, springs from the fact that, while sulfuric acid in strengths up to 62° Bé. can be handled in lead containers and in strengths over 66° Bé. can be safely heated for concentration in iron vessels, there is a gap between these in which the use of neither lead nor iron is feasible. Various processes of concentration take their names from the type of vessel they employ at this stage. In early days platinum-gold stills and fragile glass retorts were used. But even before the World War, a government publication states, "establishments of this kind are no longer erected, and the old ones are gradually dismantled and displaced through the introduction of the contact process."[36]

The acid-concentrating industry did not give up without a struggle, however, at least not before the methods of concentration had been considerably improved. One company, for example, devised a special acid-resistant substance from silica which they called vitreosil, and a system of continuous concentration whereby vitreosil dishes arranged *en cascade* are directly exposed to fire gases in open seatings, the acid flowing in counter current from dish to dish. In another system, called the Kessler concentration system, acid trickles down a tower closely packed with volvic lava through hot flue gases and acid vapor passing upward in counter current. Recently drum-type acid concentrators have been devised. In practically all types[37] removal of acid mist from the exit gases is necessary and is frequently achieved by the Cottrell electrical-precipitation process. These were some of the

[36] United States Tariff Board, *Chemicals, Oils, and Paints. Glossary on Schedule A* (Washington, D.C., 1912), p. 14.

[37] For a full technical description of various methods of concentration, see Allen Rogers, *op. cit.*, pp. 152–58.

more important improvements stimulated in part by the challenge of the contact process.

Nonetheless, the extent of such improvements has not reduced the costs of concentration sufficiently to give successful competition to the contact process. The table below, while giving data for England in the early part of 1917, reveals facts valid also in the United States: namely, considerable

TABLE 10

ITEMS OF COST IN CONCENTRATING SULFURIC ACID

(Average Cost per Ton 100% Acid for One Month)*

Item of Cost	Cascade Process		Kessler Process	Gaillard Process	
	Plant A	Plant B		Plant A	Plant B
General expense.......	$1.07	$ 1.56	$0.71	$0.70	$0.95
Maintenance	2.17	3.46	1.87	2.05	1.44
Power	0.75	1.66	0.52	0.53	0.22
Fuel	2.79	1.51	1.39	1.41	0.94
Labor	1.54	0.73	0.68	0.61	0.72
Sulfuric acid lost at $18.00 per ton.......	1.30	1.30	0.83	0.68	0.65
Total	$9.62	$10.22	$6.00	$5.98	$4.92
Outputs in tons during the month.......	1,144.8	410.0	26,830.5	21,953.5	2,183.2

* Chaplin Tyler, "Cost Analysis in Chemical Production," *Chemical and Metallurgical Engineering* (April 1926), XXXIII, 207. Tyler computed the figures from Department of Explosives Supply, *Second Report on Costs and Efficiencies for H.M. Factories Controlled by Factories Branch* (London, 1918).

variations in cost of concentration by the same process, and a good deal of difference between the processes. In no case, even at English levels of wages and costs, does the figure get down to a level of $2.50 a ton, which, as was shown above, is something like the operating differential allowed in recent years by the spread in sales price of 50° Bé. acid and oil of vitriol in the United States.

The task of summarizing the competitive status of the contact process as against the chamber process is one of the

greatest difficulty. Enormous variations exist in costs of plants using the same process, even those using the same equipment and the same general technical supervision.[38] At best only a general or idealized picture can be given. This I have endeavored to present in the accompanying table. It

TABLE 11

COMPARATIVE COSTS OF SULFURIC ACID, CHAMBER VERSUS CONTACT PROCESS

(Dollars per Ton of Sulphuric Acid, 100% Acid Basis)*

Item of Expense	Chamber Process: Dollars per Ton	Chamber Process: Percentage	Contact Process: Dollars per Ton	Contact Process: Percentage
Factory cost:				
Sulfur, 677 lbs.	$ 7.00	51.85	$ 7.02 (684 lbs.)	52.00
Niter (as anhydrous ammonia) 5 lbs.	.48	3.56		
Water, steam, and supplies, 2,500 gals.	.23	1.70	.25 (5,000 gals.)	1.85
Power, 15 kw. hr.	.32	2.37	.37 (25 kw. hr.)	2.74
Repairs	.40	2.96	.31	2.30
Labor 1.1 man hour.....	.58	4.30	.58 (1.1 man hr.)	4.30
Plant administration....	.48	3.56	.26	1.93
Taxes, depreciation, etc., on $230,000 unit of 50 tons per day capacity..	.51	3.78	1.21	8.96
Total factory cost....	$10.00	74.08	$10.00	74.08
Distribution cost:				
General and administration	.50	3.70	.50	3.70
Sales cost	1.00	7.41	1.00	7.41
Containers, etc.	.50	3.70	.50	3.70
Profit	1.50	11.11	1.50	11.11
Total of all items....	$13.50	100.0	$13.50	100.0

* Computed from data furnished by the editors of *Chemical and Metallurgical Engineering*.

assumes roughly the present (1937) level of prices and better-than-average technical efficiency. The contact plant here

[38] For charts illustrating this point even in England, see S. I. Levy, *op. cit.*, pp. 226–27.

envisaged is one of the more modern kinds, with a capacity of 50 tons per day 100 per cent acid, using vanadium catalyst and processing the raw gases.

The most important differences between the two processes shown by the table occur in the items of plant administration, taxes, and depreciation. The contact plant, costing roughly the same to build, wears out more quickly. It uses more water and slightly more power but no niter. Other expenses are practically identical. Total costs are likewise about the same.

At the present time, therefore, the two processes are on practically an even footing. They share the market about fifty-fifty, the contact process clearly having the advantage in producing oleum, oil of vitriol, and sulfuric acid of concentrated strengths, and the chamber process still being able to maintain a precarious hold on the production of sulfuric acid of weaker strengths. But should the chain of developments inaugurated by the introduction of vanadium catalysts continue to increase the competitive strength of the contact process as rapidly in the next ten years as in the last ten, the time is not far distant when the centuries-old chamber process will, as Winkler predicted thirty years ago, "be dispensed with."

VI. Competition of Raw Materials

One of the distinguishing characteristics of chemical manufacturing is its ability to make a chemically identical product from a variety of raw materials. Other industries may get their raw materials from widely spread sources, produced under varying conditions of supply, and sold in various qualities or grades; but it requires wheat to produce wheat flour, cotton to produce cotton cloth, and so on. In the chemical industries, however, the raw materials employed for a given purpose not only come from all corners of the earth but they differ in their elemental constitution. Consequently, they often require radically different processes of treatment and different sorts of equipment for production, and they come on the market not only from different regions and in different grades but in forms unsuitable for use except by firms which have more or less specialized their processes and their equipment. In choosing a different raw material producers are compelled in whole or in part to change their plant.

Producers in nonchemical manufactures are usually able in one or another fashion to begin from scratch; that is, they come to the market and, in theory at any rate, pay the same (market) price for their raw materials, their labor, and their capital. Their particular job of co-ordination, administration, and cost-minimizing is like that of other producers in the sense that all play with bundles of homogeneous units of input. The right time to buy, selecting the optimum or ideal rate of output best adapted to present and future product-demand and factor-supply, making interfactor substitutions at various intensive and extensive margins of cost accumulation—these are some of the familiar types of problems ordinarily confronting business management. In other words, all

use marbles, though the number and size used by each may vary, and by the leveling force of competition all knuckle down and are kept from fudging. In such an economic framework, competition between raw material producers merely serves to guarantee access to the market on the same terms.

But in the chemical industry there is a competition among raw materials which causes the industry or industries using them to change their processes of production. It often influences profoundly, if indeed it does not determine, the competitive success not only of processes but even of the industry itself. In short, so far as the sulfuric acid industry is concerned, no record or explanation of the success of the contact process, or even of the growth of the industry itself to a position of world leadership, can pretend to be complete which does not give considerable space to the competition among the industries furnishing the raw materials. It may be, for example, that the success of the contact process and the enormous burst of oleum production, and even some of the success in the production of dyestuffs, nitrocellulose lacquers, and the like, may be due in no small degree to the amazing development of the sulfur industry in the United States. In short, the interconnection between the economic development of the sulfuric acid industry and the fortunes of the raw material producers is too close to make possible a full understanding of the former without devoting brief attention to the latter.

The most important raw materials which are or have been used in commercial sulfuric acid manufacture here and abroad are sulfur or brimstone; pyrites; various other sulfides of iron, of copper, and of zinc; sulfur wastes from the manufacture of fuel gas; Leblanc alkali waste; and gypsum. Those most commonly utilized in the United States are listed in Table 12, below. Notice the varying amounts of sulfuric acid produced per ton of raw material, a factor of considerable importance for sulfuric acid plants far removed from

TABLE 12

Mineral Raw Materials for Sulfuric Acid*

Ore (Chemical Symbol in Parenthesis)	Region of Production	Chemical Constitution (Percentage)					Tons of 50° Bé. Acid (Theoretically Possible) from One Ton
		Sulfur	Iron	Copper	Other	Silica	
Sulfur (S)	Texas, Louisiana, Sicily	98–99.6					4.93
Iron pyrites (FeS_2)	Virginia	46.0	44.5	2.1		7.4	
	St. Lawrence, N.Y.	38.0	34.0	3.0		25.0	
	Capleton, Canada	40.2	35.2	5.1		19.4	
	Rio Tinto, Spain	48.5	40.9	4.2	0.33 arsenic	3.5	2.62
Pyrrhotite ($Fe_{11}S_{12}$)	Tennessee	35.0	40.0	5.0		18.0	1.90
Sphalerite (ZnS)	Illinois	25–28	....	...	67.00 zinc		1.63
Chalcopyrite ($CuFeS_2$)	Tennessee, Montana	34.9	30.5	34.6			1.73
Bornite (Cu_3FeS_3)	Montana	28.1	16.4	55.5			1.38
Chalcocite (Cu_2S)	Montana	20.6	1.5	77.2			1.00
Galenite (PbS)	Illinois	13.4			86.60 lead		0.66

* C. E. Munroe, "Chemicals and Allied Products," United States Department of Commerce and Labor, Bureau of the Census, *Special Reports of the Census Office*, Vol. X (*Manufactures, 1905*), (Washington, D.C., 1908), p. 407.

sources of raw material supply. Transportation expense frequently is of primary and determining importance in the competition among raw materials. Note also the valuable by-products which help to reduce raw material expense if a ready market is available for them.

Of these, by far the most important have been sulfur and pyrites. The amount of sulfur recovered from the slurry that results from the purification of manufactured fuel gases has been small, running from 1,500 to 2,500 long tons yearly.[1] The sulfur recovered from the roasting of zinc and copper ore, while equivalent to about 200,000 tons annually, will be dealt with in the next chapter because it does not enter the market except in the form of sulfuric acid even though some of it is counted as pyrites. The use of gypsum so far as the United States is concerned is still in the realm of potentiality.[2]

There are certain raw materials other than those bearing sulfur, but they are of minor importance. Air and water, of course, usually involve little or no expense, and the expense for nitrogen, as has just been shown in the previous chapter, is relatively small. Moreover, the competition between such older methods as "potting" nitrate and the newer procedure of securing it by the oxidation of ammonia has also been described. Consequently, attention in this chapter will be limited to the competition between sulfur and pyrites.

EARLY DOMINANCE OF SULFUR

During nearly all of the first hundred years of the history of the sulfuric acid industry in the United States, and certainly from 1793 to about 1880, sulfur was used exclusively.

[1] Department of Commerce, Bureau of Mines, *Mineral Resources of the United States in 1930* (2 vols., Washington, D.C., 1931), Vol. II (*Non-Metals*), p. 122.

[2] It is touched upon in chapter xii, below.

Now in many other portions of the world its use had long since been practically abandoned. As early as the year 1833 the firm Perret and Son of Lyon, France, had begun to use pyrites and in 1836 patented their furnace for burning it. But two years later enormous interest was aroused in their patent because the king of both the Sicilies granted a monopoly of Sicilian sulfur to the firm Messrs. Taix et Cie. of Marseilles, France, which promptly boosted the price of sulfur from \$25 to \$70 a ton. This proved particularly costly to the powerful Leblanc soda industry in England. Diplomatic negotiations, reinforced by warships roaming in Sicilian waters, soon brought about an abatement of price; but efforts to utilize pyrites had already met with such success (15 patents were issued in the one year, 1839) that by 1840 England had developed pyrites mines in Cornwall and Ireland. Spanish pyrites were introduced in 1856 and Norwegian in 1859, and by 1860 pyrites had completely dominated the raw material markets abroad.

It required another twenty years, however, before the burning of pyrites was even attempted in the United States, and the rest of the century before its burning became the dominant practice. The reasons seem to have been diverse.

In the first place, while from 1883 onward sulfur had been on the free list, there were tariffs on iron and copper, 20 per cent ad valorem on the former and three cents a pound on the latter. Rio Tinto ore, as we have seen in Table 12, contained 40 per cent iron and 4.2 per cent copper. A long ton of Spanish pyrites containing 92 pounds of copper would have to pay a duty of \$2.76 on the copper and roughly 66 cents on the iron, making a total of \$3.42 a ton. In 1883 the tariff on sulfur ore or "sulphuret of iron in its natural state containing not more than 3½ per centum copper" was reduced to 75 cents per ton, "provided that ore containing more than 2 per centum of copper shall pay in addition

thereto $2\frac{1}{2}$ cents per pound for the copper contained therein." In 1890 sulfur ore or "sulphuret of iron in its natural state containing in excess of 25 per centum of sulphur (except on the copper contained therein)" was placed on the free list, and in 1894 all copper ores were allowed to enter completely free of duty, where they have since remained. It is noteworthy that imports of pyrites jumped immediately and that the period from 1895 to 1900 marks a quinquennium when the sulfuric acid industry changed over almost completely from sulfur to pyrites.

In the second place, domestic production was in no way able to furnish an adequate supply of pyrites. No mines were known or were sufficiently developed near adequate and cheap transportation facilities to permit their competing effectively with sulfur. Several ore bodies were discovered and developed, but none of large dimensions. Pyrites from the Milan Mines of Copperville, Coos County, New Hampshire, for example, cost \$1.70 to mine and \$1.00 to ship to the nearest market (Boston) and \$1.25[3] to transport to the biggest markets, New York and Philadelphia. The Armenius Mines of Louisa County, Virginia, similarly could deliver only twelve to twenty thousand tons at about \$3.00 a ton. The Davis Mines in Franklin County, Massachusetts, while producing somewhat more than 50,000 tons in the 'eighties, were similarly far from a seaport or railway center. Not only did this remoteness of the mines from their markets put the domestic pyrites producers at a considerable disadvantage with ore that could come by sea, a fact which led them to fight hard to retain the tariff,[4] but when the ore

[3] Richard P. Rothwell, "Pyrites," in Department of the Interior, United States Geological Survey, *Mineral Resources of the United States 1886* (Washington, DC., 1887), p. 653.

[4] See the testimony of pyrites producers in *Report of the United States Tariff Commission,* 47th Cong., 2d Sess. (House of Representatives, Miscellaneous Doc. 6) (2 vols., Washington, D.C., 1882), II, 1365, 1369, 1420, 1657, 2285, and 2497.

reached the sulfuric acid plants from 15 to 30 per cent of it had been shaken into powder or "fines." Inasmuch as no furnace had up to 1896 been completely successful in burning fines, kilns being generally used for egg-sized ores, the cost of domestic pyrites was further increased.

In the third place, it was considerably simpler and required no learning and teaching of new techniques to continue to burn sulfur. Even though pyrites was less expensive per unit of sulfur, to burn it meant

> handling into the works a comparatively large quantity of material, its slow combustion in expensive roasters, a certain inevitable dust nuisance and the disposal of a large tonnage of cinder. As against this, sulphur of less than one-half the weight of pyrites for a given tonnage of acid produced is handled into the works, is burned cleanly in inexpensive equipment and leaves no residues to be taken care of.[5]

Sulfur gives a hotter gas than does pyrites, with a 50 per cent greater content of sulfur dioxide, so that less chamber space is needed to produce the same acid. Moreover, the furnaces are less complicated and less labor is needed. Finally, the product is chemically pure, whereas when ores are used as a supply of sulfur the resultant sulfuric acid is likely to contain impurities such as lead, arsenic, iron, nitrous oxides, nitric acid, calcium, and copper, some of which may under certain circumstances be of such considerable industrial importance as to require removal by a more or less expensive process of purification.

PYRITES COMPETITION BEGINS

The period from 1880 to 1895 was a period of much debate in the technical journals on the relative merits of pyrites and sulfur. On the one hand there were those who contended that chamber acid could not be made cheaper

[5] De Wolf and Larison, *op. cit.*, p. 33.

from pyrites than from sulfur. Others maintained that the materials had equal competitive status. And a third group gave the advantage to sulfur. All of them started with different assumptions concerning prices, concerning efficiencies of plant and labor, levels of output, policies of depreciation and obsolescence, and so forth. A comparison of their estimates yields an instructive picture of the varieties of relationships present in the business of making sulfuric acid in that period.

In Table 13 three of the most competent of these estimates have been brought together. All are made by practical technicians who are describing current practice. Yet they come to divergent conclusions. Estimator A, the one who finds sulfur the cheapest, gets as much acid from 2½ tons as estimator C, the one who finds it most expensive, gets from 3 tons. He finds that depreciation and interest on investment amount to 78 cents per ton, while C sets the figure at $1.01. Thus A produces sulfuric acid from sulfur for $6.22 and C for $6.80. On the other hand, when pyrites is the raw material, A finds his labor expense per ton of 50° Bé. acid equal to 95 cents a ton and C finds his equal to 64 cents; A finds his expense for pyrites $3.00 (using a lower grade domestic ore in the interior), while that of C is $2.46 (using Spanish pyrites at the seaboard). Consequently A's acid costs him $6.25, or slightly more than if he used sulfur; while C's acid costs him $5.50, or 20 per cent less.

In general, prior to 1895, comparing these estimates on the basis of highest common multiple of agreement, we find that pyrites furnished sulfur content per ton of acid at three-fifths to three-fourths the cost of brimstone. Niter expense was slightly higher and labor expense considerably higher if not double that incurred when brimstone was the raw material. The investment required being from one-third to one-half greater per ton/day of acid produced, depreciation and

TABLE 13

Cost of Sulfuric Acid from Sulfur versus Pyrites

Item of Expense	Advantage with Sulfur[a] Estimate A		Equal Advantage[b] Estimate B		Advantage with Pyrites[c] Estimate C		Cost per Ton 50° Bé. Acid A	B	C
Sulfur	2½ tons (5,600 lbs.) at $21..	$52.50	2½ tons at $21–$29..	$52.50–$72.50	1 ton "thirds" 98% sulfur.	$19.00	$3.94	$4.36–$6.03	$4.22
Niter	225 lbs. (4% per pound per day of sulfur) at $.02	4.50	200 lbs. at $.025.....	5.00– 5.00	50 lbs. at $.025............	1.25	.34	.42– .42	.27
Sulfuric acid	220 lbs., 60° Bé. at $.40 per 100	.88	200 lbs. at $.40 per 100	.80– .80			.07	.07– .07	...
Labor	4 men at $1.50 (2 firemen)	6.00	2 men at $1.25.......	2.50– 2.50	Workmen's wages	2.25	.46	.21– .21	.55
Depreciation	$.40 per ton of acid produced	5.40	Wear and tear......	6.00– 6.00			.40	.50– .50	...
Repairs	$.20 per ton of acid produced	2.70			General jobbing repairs...	.50	.20	....	.11
Fuel, light, etc.	....	2.00			5 cwt. coal at $4 per ton..	1.00	.15	....	.21
Office expenses .	....	5.00		5.00– 5.00	Superintendence and management	2.00	.38	.42– .42	.43
Interest on investment		5.00			Interest on capital of $75,000	4.60	.38	....	1.01
Product	13½ short tons.........	$83.98	12 tons	$71.80–$91.80	4½ tons	$30.00	.22	$5.98–$7.65	$6.80

Pyrites	5½ tons (12,320 lbs.) 37% available sulfur at $6	$33.00	5 tons at $5–$8	$25.00–$40.00	2½ tons, 46% sulfur	$11.50	$2.77–$4.43	$2.46
Niter	180 lbs. (4% per pound per day of sulfur at $.02	3.60	270 lbs. at $.025	6.75– 6.75	60 lbs. at $.025	1.50	.75– .75	.32
Sulfuric acid	250 lbs., 60° Bé. at $.40 per 100 lbs.	1.00	360 lbs. at $.40 per 100 lbs.	1.45– 1.45			.16– .16	
Labor	Breaking of pyrites and moving cinder	1.40	Breaking ore and loss	1.25– 1.25			.14– .14	
	6 men at $1.50 (2 firemen for boiler)	9.00	4 men at $1.25	5.00– 5.00	Workmen's wages	3.00	.56– .56	.64
Depreciation	$.50 per ton of acid produced	5.50	Wear and tear	9.00– 9.00			1.00– 1.00	
Repairs	$.25 per ton of acid produced	2.75			General jobbing repairs	.60	....	.13
Fuel, light, etc.	....	2.00			5 cwt. of coal at $4 per ton	1.00	....	.21
Office expenses		5.00		5.00– 5.00	Superintendence and management	2.00	.56– .56	.42
Interest on investment		5.50			Interest on capital of $100,000	6.15		1.32
Product	11 short tons	$68.75	9 tons	$53.45–$68.45	4½ tons	$25.75	.25 | $5.94–$7.60	$5.50

[a] Taken from Department of the Interior, United States Geological Survey, *Mineral Resources of the United States, 1893* (Washington, D.C., 1894), p. 744.

[b] Taken from J. H. Kelley, "Comparative Value of Brimstone and Pyrites in the Manufacture of Sulphuric Acid," *Engineering and Mining Journal* (July 23, 1892), Vol. LIV, No. 4, p. 76.

[c] Taken from Richard P. Rothwell, "Pyrites," Department of the Interior, United States Geological Survey, *Mineral Resources of the United States, 1886* (Washington, D.C., 1887), p. 671.

interest on investment were correspondingly greater, assuming equal wear and tear. If anything, the rate of using up the equipment was faster for that designed to make sulfuric acid from pyrites than for that from brimstone. Therefore, the net advantage did not seem to lie to such an extent with the kind of raw material used as it did with such factors as technical efficiency, special access to raw materials, closeness to markets, and the like.

Consequently the shift from sulfur to pyrites was at first not rapid, and that which did occur took place for the most part in seaport areas such as New York, Boston, and Philadelphia. In 1880 only three plants burned pyrites—Watson and Clark at Philadelphia and the Lodi Chemical Works in New Jersey using the ordinary English kiln, and the Phoenix Chemical Works of Brooklyn, New York, using a German shallow kiln. The other 46 plants enumerated by the census burned sulfur. In 1885 the number using pyrites as raw material had increased to 23, two using the Canadian product, six the Spanish article, and fifteen domestic pyrites.[6] Only three of these plants used mechanical furnaces, nine using grate burners and two having installed shelf burners. The amount of pyrites consumed had increased from 8,000 tons in 1881 to 96,400 tons in 1885. By 1891 the total had reached 290,000 tons, of which 160,000 tons were used by plants in the New York district and another 95,000 tons were consumed in the Boston and Philadelphia districts.[7] While in 1882 over 85 per cent of sulfuric acid was made from brimstone, by 1895 the amount had fallen to 75 per cent.

[6] William Martyn, "Pyrites," in Department of the Interior, United States Geological Survey, *Mineral Resources of the United States for 1883 and 1884* (Washington, D.C., 1885), p. 886.

[7] W. H. Adams, "Pyrites as a Material for the Manufacture of Sulfuric Acid," *Journal of Analytical and Applied Chemistry* (1892), Vol. VI, No. 1, p. 22.

PYRITES THE DOMINANT RAW MATERIAL

In less than ten years the amount of sulfuric acid obtained from sulfur had fallen to less than 20 per cent. In the year 1900 the census of manufactures lists 77 plants using pyrites, 31 utilizing brimstone, 17 using both, and 2 plants processing the waste gases in zinc smelting. By 1905 the figures had become 114, 19, 10, and 5, respectively, with 5 plants recovering their spent or sludge acid.[8] In 1900 the amount of pyrites used was roughly 720,000 tons—more than three times the figure (225,000 tons) of 1890.

Moreover, the cost of pyrites acid had become unmistakably lower than that of acid from brimstone by 10 to 20 per cent. Two American manufacturers estimate the costs of 10,000 tons of 50° Bé. acid in a plant at Newark, New Jersey, in the period from 1900 to 1905 as follows:

TABLE 14

COSTS OF SULFURIC ACID FROM PYRITES AND FROM SULFUR, 1900–1905*

Item of Expense	Pyrites		Sulfur	
Raw materials	(3,776.68 long tons at $7.00)	$26,436	(2,075 tons at $17)	$35,275
Niter at 2 cents per pound...		1,660		1,660
Coal for air and steam.....		2,400		1,800
Labor (one manager).......		500		1,500
Chambermen	(two)	1,400	(two)	1,400
Furnacemen	(four)	200	(two)	1,100
Laborers	(four)	600	(one)	400
Repairs		1,000		700
Interest—6 per cent investment in plant and working expenses		6,180		6,000
Insurance, taxes, water, and office expenses		6,342		6,200
Depreciation of plant.......	(2%)	1,300	(1½%)	1,120
Cost per ton of 50° Bé. acid..		5.07		5.60

* Lunge, *op. cit.*, Vol. I, Part III, p. 1258.

[8] C. E. Munroe, "Chemicals and Allied Products," United States Department of Commerce and Labor, Bureau of the Census, *Special Reports of the Census Office*, Vol. X (*Manufactures, 1905*) (Washington, D.C., 1908), p. 406.

Two developments were of especial importance in causing the shift from sulfur to pyrites. The first was a considerable rise in the price of sulfur after 1895 due to the organization for the second time of a virtual (85 per cent) Sicilian monopoly. In 1890 the English Leblanc soda industry developed the Chance-Claus process for the recovery of sulfur from the millions of tons of alkali waste lying about their acid works. The threat was sufficiently great to produce cutthroat competition among the Sicilian producers, and the price of sulfur broke, as is shown in Table 15 below, from levels around $23 per ton in 1891 to $13 and less in 1895, out of which had to be paid an export tax of $1.95 a ton. In 1896 the Sicilian laborers were on the verge of starvation and revolution. Efforts "originating in England resulted in the . . . . formation of the Anglo-Sicilian Sulphur Company. This combination received the support of the Italian Government which reduced the export tax on sulphur to one lira [19.3 cents] per ton."[9] Wages were raised, child labor was abolished, and mechanical apparatus for hoisting was gradually introduced, but not without opposition. Laborers wished a continuation of the old method whereby ore in baskets and sacks was carried to the surface along inclined paths on the side of the excavations. Moreover, the price of sulfur was raised considerably, miners being guaranteed by the Società Anglo-Siciliana $15.94 per ton for best unmixed seconds.

Notice in Table 15 that in the three years from 1895 to 1898 the average value of sulfur imports into the United States increased from $12.80 a ton to $19.10. In the same years the price of imported pyrites continued downward from $3.50 to $2.80 a ton. As a result the sulfur content of

[9] United States Tariff Commission, *Tariff Information Survey FL 18, Sulphur and Pyrites, Fulminates and Explosives* (Washington, D.C., 1921), p. 24.

TABLE 15

AVERAGE PRICE OF IMPORTED SULFUR, IMPORTED PYRITES, AND DOMESTIC PYRITES, 1882–1903 (TO NEAREST TEN-CENT FIGURE)*

Year	Imported Sulfur		Domestic Pyrites (38% Sulfur)		Imported Pyrites (40% Sulfur)	
	Dollars per Ton	Per Ton of 50° Bé. Acid[a]	Dollars per Ton	Per Ton of 50° Bé. Acid[b]	Dollars per Ton	Per Ton of 50° Bé. Acid[c]
1882........	$27.00	$6.00	$6.00	$3.00	....	....
1883........	24.20	5.40	5.50	2.75	....	....
1884........	21.40	4.80	5.00	2.50	....	....
1885........	20.10	4.50	4.50	2.25	....	....
1886........	19.00	4.20	4.00	2.00	....	....
1887........	17.40	3.90	4.00	2.00	....	....
1888........	16.10	3.60	3.10	1.55	....	....
1889........	15.20	3.40	2.20	1.10	....	....
1890........	16.90	3.80	2.75	1.40	....	....
1891........	22.90	5.10	3.20	1.60	$3.90	$1.56
1892........	21.70	4.80	2.80	1.40	3.80	1.52
1893........	18.00	4.00	3.40	1.70	3.70	1.48
1894........	13.60	3.00	3.40	1.70	3.60	1.44
1895........	12.80	2.80	3.30	1.65	3.50	1.40
1896........	14.30	3.20	2.80	1.40	3.20	1.28
1897........	17.50	3.90	2.70	1.35	2.90	1.16
1898........	19.10	4.20	3.10	1.55	2.80	1.12
1899........	17.70	3.90	3.10	1.55	4.00	1.60
1900.......	17.50	3.90	3.60	1.80	3.30	1.32
1901........	18.70	4.20	3.70[d]	1.85	3.50	1.40
1902........	18.70	4.20	3.90[d]	1.95	3.70	1.48
1903........	19.30	4.30	3.80[d]	1.90	3.90	1.56

* Data computed from tonnage and value figures given in successive numbers of *Mineral Resources in the United States* issued by Department of the Interior, United States Geological Survey.

[a] Assuming that one ton of sulfur will produce 4½ tons of 50° Bé. acid.

[b] Assuming that one ton of American pyrites will produce two tons of 50° Bé. acid.

[c] Assuming that one ton of Spanish pyrites will produce 2½ tons of 50° Bé. acid—a relatively high yield but one justified by Dr. Lunge's figures in the preceding table that 3,776 tons of pyrites produce 10,000 tons of 50° Bé. acid.

[d] Canadian pyrites. Figures for the United States have a good deal of sulfur lumped with them.

a ton of 50° Bé. acid when got from pyrites cost less than one-third the amount when obtained from sulfur.

A further factor influencing the price policy of the brimstone syndicate may have been the fact that a number of other uses developed for sulfur between 1890 and 1900. Considerable quantities of it were used by the contact acid industry to make oleum for sulfonation processes in the coal-tar chemical industry, especially dyestuffs. Medicinal and other users requiring pure sulfuric acid also added to the demand for sulfur. Moreover, the paper industry required increasing amounts of it for sulfite wood pulp, as did the rubber industry for purposes of vulcanization. Consequently the sulfur monopoly let the sulfuric acid market go and pushed their sales in other directions.

The second development of particular importance in accounting for the extraordinarily rapid shift from sulfur to pyrites in the five-year period from 1896 to 1901 was the invention of mechanical burners for handling pyrites both in furnace size and in "fines" sizes, especially the Herreshoff furnace in 1896. The technical advantages of this furnace have been explained in the foregoing chapter. It will suffice here to point out that with this new furnace the pyrites "fines" that formed 15 to 30 per cent of the domestic product after its long journey to acid works could be fully utilized. Where previously one man could handle only about 3 tons of "fines" per day and 5 tons of egg-size pyrites, he now could handle 50 tons. In other words, the labor cost was brought down to a level only moderately higher than that incurred with sulfur as the raw material.

A further factor here was the circumstance that the industry which was rapidly consuming more sulfuric acid was the phosphate-fertilizer industry. To it the matter of impurities such as arsenic and lead, if in moderate amounts, was of no consequence. Two of the three companies, the Virginia Carolina Chemical Company, the American Agricultural Company, and the Standard Oil Company, which were said in

1903 to consume 90 per cent[10] of the total output of domestic sulfuric acid, were and are manufacturers of fertilizer.

By 1914 sulfur had been almost completely ousted as a raw material for sulfuric acid. Imports of Spanish pyrites, which prior to 1890 had been less than 20,000 tons and grew to 300,000 tons by 1900, had become 700,000 tons in 1910 and 900,000 tons in 1914. Five firms dominated the market: the Pyrites Company (Ltd.), with plants for leaching and sintering pyrites cinder at Wilmington, Delaware, and Roanoke, Virginia; the Pennsylvania Salt Manufacturing Company, with leaching and nodulizing plants at Philadelphia and Natrona, Pennsylvania; Naylor and Company, the Davis Sulphur Ore Company, and Ladenburg, Thalman and Company—all of them with offices in New York. Freight rates from Spanish ports to New York ranged from \$2.25 to \$2.50 a ton. Prices varied from 10 to 12 and 12½ cents a unit of sulfur, and the iron in the cinder was generally worth \$1.50 a ton. Thus the amount of sulfuric acid made from Spanish pyrites amounted to nearly one-half of the total production in the United States. Domestic pyrites accounted for another sixth and by-product copper and zinc ores for about a fourth, and only 2.6 per cent of the American sulfuric acid produced in 1914 was made from sulfur. The triumph of pyrites was complete.

DOMESTIC SULFUR ENTERS WORLD MARKETS

But in the sulfur industry the stage had already been set for a vigorous resumption of competition. As early as the year 1865 a large deposit of sulfur was discovered in Calcasieu Parish, Louisiana. Several early attempts had been made to mine it, notably one by a French company in 1884, but all of them had proved disastrous both to life and to

[10] Department of Interior, United States Geological Survey, *Mineral Resources of the United States 1903* (Washington, D.C., 1904), p. 1084.

capital because of inability to go through the layers of quicksand impregnated with poisonous hydrogen sulfide gas that overlay the deposit. In 1903, however, after years of failure, the persistent efforts of Herman Frasch (he took out the first patent in 1891) finally succeeded in perfecting a process that proved eminently successful.

It consists in fusing the sulfur deposits *in situ* by superheated water. The holes are drilled to a depth of 800 feet or more and concentric pipes are sunk in. The superheated water is forced down the outer annular spaces under a pressure of six atmospheres. Then, by admitting compressed air through one of the pipes on the emulsator principle, the melted sulfur is forced up another pipe, usually made of aluminum.

To the incredulous amazement of the Anglo-Sicilian sulfur producers, sulfur began to be pumped out of the ground on a large scale by methods utilizing little labor but requiring heavy capital investment. By running the melted sulfur into huge wooden tanks and allowing it to solidify, quasi-mountains of sulfur, sometimes sixty-five feet high, began to accumulate. Soon more than a million tons were known to be in reserve, shipment from which simply meant blasting the sulfur loose, loading it into gondola carts by locomotive cranes equipped with grab buckets, and emptying the cars by automatic loading machinery. This could be done so quickly that steamers were able to dock, load, and sail in twelve hours.

This was a type of competition which the Sicilian sulfur monopoly found difficult to meet. It was ideally adapted to American conditions, requiring little labor but utilizing expensive and elaborate machinery, supervised by highly trained technicians, and operating continuously. By contrast, in Sicily sulfur was still mined in open pits two hundred to five hundred feet in depth and carried by laborers in baskets

or sacks up inclined paths; then the sulfur was melted in *calcerones* with a loss of about one-third of the sulfur content. No wonder the large-scale methods of the Union Sulfur Company brought swift readjustments in the world's sulfur business! In the first full year of production, 1904, 190,000 tons of sulfur were produced.

The suddenness of the transition is strikingly epitomized in Table 16. In the seven years between 1911 and 1918 production of sulfur in the United States jumped nearly sevenfold, from around 200,000 to 1,350,000 tons. Sicilian production was cut in two. In the short space from 1903 to 1907, domestic imports went down from 189,000 to 20,000 tons, only the Pacific Coast continuing to get a small supply from Japan.

TABLE 16

UNITED STATES AND SICILIAN SULFUR PRODUCTION AND TRADE, 1901–1918
(Thousands of Tons)*

Item	1901	1903	1905	1907	1909	1911	1914	1916	1918
Domestic production	7.0	35	215	308	274	205	418	650	1,353
Sicilian production	554.0	545	560	420	428	408	372	265	230
Domestic imports	174.0	189	83	20	29	29	26	21	0.055
Domestic exports	0.2	1	7	18	31	17	98	129	131
Domestic consumption	180.0	223	258	295	254	265	270	659	1,136

* For detailed data annually and sources, see Tables 21, 22, and 23.

In the meantime Sicilian exports fell off even more rapidly than production, for the United States in the first years of the twentieth century had taken nearly a third of her product, being her best customer. By 1906 fairly large stocks of it (about 400,000 tons) had accumulated, causing the syndicate to shut down. Thirty thousand workers were thrown out of employment, and the Anglo-Sicilian Sulphur Company exercised the option it had been given at the time of its formation in 1896 whereby its agreement covering 85 per cent of Sicilian production to buy their output at a fixed price

could be terminated. Poverty and unrest grew to such proportions as to cause the Italian government to intervene. It organized a monopoly of sales and production in the hands of a consortium called *Consorzio Obligatorio per l'Industria Solfifera Siciliana.* The export tax was removed and a disguised subsidy was given in the form of a 50 per cent reduction in railroad rates on sulfur for export. In 1907 a *modus vivendi* was worked out with the Union Sulfur Company by reserving the Mediterranean market to the Sicilians and the American market to the American producer.

The American producers held the price of sulfur unchanged at $22 a ton, being content to supply the growing demand for sulfur domestically and not building an export business exceeding 100,000 tons until the advent of the war. Thus the sulfuric acid industry continued to use pyrites, except when it produced oleum and acid of similar strengths by the contact process.

WORLD WAR BRINGS SUDDEN SHIFT BACK TO SULFUR

Among the changes in the sulfuric acid industry that occurred during the World War one would probably have taken place in any case: the resumption of the competitive struggle between sulfur and pyrites. For in 1908 the Freeport Sulphur Company began operations on its Bryant Heights property some forty miles from Galveston, Texas, believing that the expiration of the original Frasch patent made the process public property, a belief which received vindication in the courts.[11] In 1919 the Texas Gulf Sulphur Company began

[11] This case is of more than ordinary interest because it shows how unpatentable certain crucially important scientific information really is. The process is relatively simple. The factors which Frasch had the stamina and courage to spend a dozen years to find out were the requirements for making the process applicable: "first, that the sulphur-bearing formation shall be sufficiently porous to permit the flow of hot water through the rock; second, that the cap rock shall be sufficiently deep but not too deep below the surface, so that the hydrostatic pressure on the formation shall be sufficient to keep water at the melting

producing in its plant at Matagorda Hill, Texas, at the rate of 1,500 tons a day, and in less than a year production was stepped up to 2,500 tons a day. The three companies could produce about two and a half million tons a year, or three times the normal prewar world consumption. Except for the war such a development would have come later, but it would probably have come nonetheless.

Be that as it may, in actual fact because of the war it took sulfur less than three years to seem to reconquer one-half of the domestic sulfuric acid market. As is evident in Table 17, the production of sulfuric acid from sulfur rose

TABLE 17

RAW MATERIALS FOR SULFURIC ACID, 1903, 1914, 1917, 1918*

Raw Material Burned	1903		1914		1917		1918	
	Tons 50° Bé. Acid Produced	Percentage of Total	Tons 50° Bé. Acid Produced	Percentage of Total	Tons 50° Bé. Acid Produced	Percentage of Total	Tons 50° Bé. Acid Produced	Percentage of Total
Sulfur	375,728	18.2	100,000	2.6	2,350,000	32.6	3,580,000	48.0
Pyrites								
Spanish, Domestic, Canadian	1,445,937	72.0						
Spanish			1,900,000	50.0	1,650,000	22.9	570,000	7.6
Domestic			600,000	15.8	850,000	11.8	950,000	12.7
Canadian			300,000	7.9	500,000	6.9	550,000	7.5
Zinc ores	125,000	6.1	500,000	13.2	1,300,000	18.1	1,200,000	16.1
Copper ores	76,000	3.7	400,000	10.5	550,000	7.7	600,000	8.1
Total	2,021,665	100.0	3,800,000	100.0	7,200,000	100.0	7,450,000	100.0

* A. E. Wells and D. E. Fogg, *Manufacture of Sulphuric Acid in the United States* (Department of the Interior, Bureau of Mines, Bulletin 184, Washington, D.C., 1920), pp. 23 and 24.

precipitately during the World War, but more than three-fourths of it went into the manufacture of explosives. For in

point of sulphur from flashing into steam; and third, there must be sufficient sulphur to pay for the large installation cost of the necessary plant." "Chemical Industry's Contribution to the Nation, 1635–1935," Supplement to *Chemical Industries* (May 1935), p. 86.

1918, on the average, every pound of smokeless powder manufactured from cotton linter required 2.3 pounds of sulfuric acid (100 per cent basis), every pound of TNT from toluol 2.2 pounds, and every pound of picric acid from benzol 6.5 pounds.[12] Out of a total estimated sulfuric acid production in that year of 7,450,000 tons, more than a third, or 2,700,000 tons, went into the production of explosives. Thus initially there was no displacement but rather a supplementation. Early in May 1917 the Chemicals Committee of the Council of National Defense arranged in view of the certain and almost immediate exhaustion of pyrites stocks that sulfur be shipped to fertilizer companies at $22 a gross ton, mine. When in August 1917 sulfur, pyrites, and sulfuric acid came under the provisions of the Food Control Act, licenses were required by the United States Food Administration for all dealers whose gross sales amounted to more than $100,000.

The serious inroads upon shipping made by the submarines and the pressing need of the remainder for transport of men and munitions resulted early in 1918 in an agreement between the government, the producers, and the consumers whereby licenses for only 125,000 tons of pyrites imports from Spain and Portugal would be granted between April 1 and October 1.[13] Coupled with this the expedient was at first considered of increasing the supply of domestic pyrites; but engineers, machinery, and workmen could not wisely be diverted from war activities to the development of relatively small and unimportant pyrites ore bodies. The small amount of stimulation which the government did attempt resulted in some cases in losses to pyrites producers (also to manganese, chromium, and tungsten producers), for the re-

[12] Wells and Fogg, *op. cit.*, p. 20.

[13] Department of the Interior, United States Geological Survey, *Mineral Resources of the United States 1918* (2 vols., Washington, 1921), Philip S. Smith, "Sulphur and Pyrites," Vol. II (*Non-Metals*), pp. 360–61.

imbursement of which in March 1919 a War Minerals Commission was set up in the Department of the Interior. Coal brasses (marcasite) obtainable to the extent of about half a million tons from certain bituminous coal mining sections could be cleaned of attached carbon; but this meant increased mining of coal, transport to central washeries, and at best a fairly low-grade material (40 per cent sulfur) producing a sulfur dioxide gas in the burners seriously diluted with carbon dioxide, and a dark-colored acid.

Accordingly, in July 1918, the War Industries Board marshaled the resources of the United States government behind the effort to develop a reliable and sufficient supply of domestic sulfur. "Permission was granted the Texas Gulf Sulphur Company to develop at their [government] expense a sulfur deposit, drillings showing a large deposit of brimstone with good cover. This property came in production early in 1919."[14]

These two factors, the demand for concentrated acid to make explosives and governmental encouragement of sulfur development, no doubt hastened considerably the shift from pyrites to sulfur; but the industry was ready to compete on a pure cost basis. In 1917, for example, researches by the Bureau of Mines established the fact that in general Spanish pyrites priced at $6.75 was of equal status with sulfur at $18.50. Their computations reproduced in Table 18, below, indicate that improvements in the art of burning sulfur had gone so far as to make the labor cost less than one-half of that needed for pyrites, and the capital costs one-sixth. The cost figures are an average taken from the actual operating data in a number of plants. At individual plants there are of course variations due to differences in sulfur content of the available pyrites ore, differences in transport cost, differences

[14] Charles H. MacDowell, "Sulphuric Acid Prices Will Be Higher," *Chemical and Metallurgical Engineering* (May 1926), Vol. XXXIII, No. 5, p. 321.

in revenue obtained from by-product copper or iron in the cinder, differences in plant equipment for handling pyrites, and so forth. They show, therefore, that to many plants with pyrites at $6.75 a ton delivered sulfur might be attractive at even higher prices than $18.50.

TABLE 18

COSTS OF SULFURIC ACID FROM PYRITES AND FROM SULFUR, 1917*

Item	Pyrites		Sulfur	
Material equivalent to 10 tons of sulfur..	23.3 tons 45% pyrites fines at $6.75.......	$157.25	10.1 tons at $18.50...	$187.00
Handling and roasting ore..	$1.10 per ton.........	25.65	$.60 per ton.........	6.00
Handling cinder	17.5 tons at $.25.....	4.37		
Repairs to and depreciation of burner plant...........	10 per cent..........	6.00	10 per cent...........	1.00
Total expense		$193.27		$194.00

* Wells and Fogg, *op. cit.*, p. 25.

Now eighteen dollars and fifty cents a ton in 1917 was a not altogether unprofitable price. For, according to an investigation made by the Federal Trade Commission, "the cost to the Freeport Sulphur Company in 1917 was $6.15 per ton; in 1918 it is estimated that increases will bring the cost up to not over $9.50 per ton. In the first part of 1917 the Union Sulphur Company's costs were $5.73 per ton."[15] Freight charges on sulfur in minimum cargoes of 30,000 pounds from Houston and Texas City, Texas, to Philadelphia were $8.90 per ton, and from Galveston, Texas, where the Texas Gulf Sulphur Company has its electrically operated sulfur-loading plant with belt conveyors, aluminum-spout locomotive cranes, and so forth, the freight to New York City

[15] Federal Trade Commission, *Official Bulletin* (Washington, 1918), Vol. II, No. 348, p. 13.

is $11.90 per ton.[16] From these figures totals ranging from $14 to $18 per ton can be derived, indicating the level to which the prices of sulfur could have been lowered by sulfur producers in order to gain a foothold in the sulfuric acid market.

One final factor requires mention to complete the story of the sudden utilization of sulfur in the sulfuric acid industry during the World War. That is the fact that the price of pyrites (Spanish crude, 48 to 52 per cent, export shipment), which had been remarkably stable at 10½ to 11 cents a unit (a unit is 22.4 pounds of sulfur, thus 50 per cent pyrites would cost 50 × 11 or $5.50 a ton) from the middle of 1912 to the end of 1915, jumped to from 15 to 15½ cents a unit during 1916 and to 17 cents in 1918[17] At $8.50 a ton it was more expensive as a raw material than sulfur at $22.50, which was the price the sulfur producers had charged for the long period from 1908 to the beginning of 1916 and the figure at which allocations were officially made to fertilizer and explosives plants during the war. Thus commercial reasons alone were sufficient to induce a considerable shift by acid producers to the use of sulfur.

POSTWAR CONSOLIDATION OF GAINS BY SULFUR

The acid test of the competitive status of sulfur came immediately after the World War, with results that are strikingly shown in Figure 8. Notice that domestic consumption of pyrites reached a peak of 1,683,794 tons in 1916, from which it fell by nearly 80 per cent to 373,347 tons in 1921. From this level it recovered considerably during the 'twenties, but even at the peak in 1929 it was just barely one-half of the war total, and only two-thirds of the prewar figure in 1912. Pyrites imports fell from the prewar level of about a

[16] United States Tariff Commission, *Tariff Information Survey FL 18, Sulphur and Pyrites, Fulminates and Explosives* (Washington, D.C., 1921), p. 30.
[17] *Ibid.*, p. 20.

million tons to a 1922–1927 level of about 275,000 tons. There was a jump from 250,794 tons in 1927 to 458,264 tons in 1928, owing for the most part to the acquisition by the Spanish Rio Tinto pyrites interests of control over large fertilizer outlets in the United States.

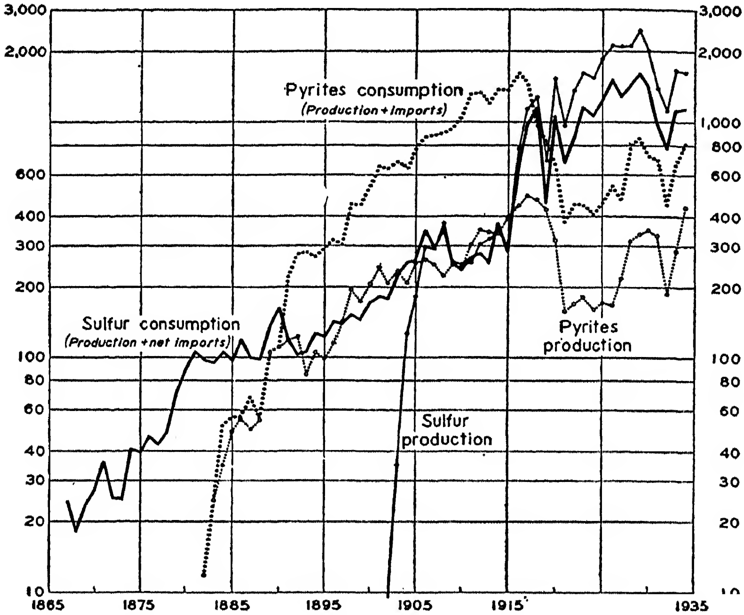


Fig. 8.—Consumption and production of sulfur and pyrites, 1870–1935. For sources of data, see Tables 21, 22, and 23.

Domestic production of pyrites similarly fell to a level around 300,000 tons, about one-half of that enjoyed in the five-year period before the World War.

In 1934 the statistics show a notable increase, production jumping from 284,311 tons in the previous year to 432,524 tons. This is due to increases in flotation concentrates coming from increased copper and zinc production. The old-line lump pyrites production in 1934 was only 91,082 tons. As a result Virginia, which had for decades ranked first as a pro-

ducer, has been supplanted by Tennessee, which began to produce pyrites and pyrrhotite concentrates in 1925. From a figure of 23,561 long tons in that year, its production increased in 1929 to 169,101 tons,[18] more than one-half of the total production of pyrites in the United States.

Some of the most important producers are sulfuric acid concerns, as, for example, the Tennessee Copper Company and the Ducktown Chemical and Iron Company. Likewise all the product of the Gossan mine at Cliffview, Carroll County, Virginia, is sent by the General Chemical Company to its sulfuric acid plant at Pulaski. This company also processes in its Denver plant the pyrites produced in Colorado from the mill-tailings dump of the Colorado Zinc-Lead Mill in Lake County. Similarly in California the Leona Heights Mine operated by the Leona Chemical Company sends its product for conversion into sulfuric acid to the Stauffer Chemical Company. The pyrites produced in Montana are produced and converted by the Anaconda Copper Mining Company at Anaconda. All together, only a third of domestic pyrites production is sold (96,874 tons out of a total production of 284,311 tons in 1933). The rest is consumed by the producers almost entirely in the manufacture of sulfuric acid.

A certain proportion of the pyrites produced is a by-product of zinc mining. In 1934 the St. Joseph Lead Company produced 31,674[19] tons of pyrites as a flotation concentrate in the treatment of zinc ores at its mine in St. Lawrence County, New York. Similarly in Wisconsin the Vinegar Hill Zinc Company produces pyrites at its magnetic separation plant at Cuba City from raw zinc concentrates. The fifteen to twenty thousand tons produced in Missouri, while mostly

18 United States Department of Commerce, Bureau of Mines, *Mineral Resources of the United States 1929* (2 vols., Washington, D.C., 1929), Vol. II (*Non-Metals*), p. 188. The figures include a small amount of by-product pyrites from zinc operations in Wisconsin.

19 United States Department of the Interior, Bureau of Mines, *Minerals Yearbook 1935* (Washington, D.C., 1935), p. 1025.

marcasite, are shipped for roasting to the Evans-Wallower Zinc Company at East St. Louis, Illinois, and to the Titanium Pigment Company at St. Louis, Missouri.

While no figures are available in recent years showing the manner in which competitive forces vary in their composition from plant to plant, the extent and the existence of such diverse plant conditions is shown clearly by the figures for 1918 epitomized in Table 19, below.

TABLE 19

PYRITES PRODUCTION, BY STATES, 1918*

State	Amount (*Long Tons*)	Value	Average per Ton
California	111,861	$ 501,541	$4.48
Colorado	18,817	115,712	6.15
Georgia	31,315	268,797	8.58
Illinois	24,369	85,659	3.52
Missouri	7,674	69,202	9.02
New York	63,982	422,958	6.61
Ohio	9,845	40,215	4.08
Virginia	143,427	841,177	5.86
Other States	53,204	299,254	5.62
Total	464,494	$2,644,515	$5.69

* Department of the Interior, United States Geological Survey, *Mineral Resources of the United States 1918* (2 vols., Washington, D.C., 1921), Vol. II (*Non-Metals*), p. 371.

The fact appears clearly that pyrites production in the United States has definitely become a by-product of copper, lead, or zinc operations. Supported by such joint products it is in a virtually impregnable competitive position.

The continued utilization of imported pyrites, however, will definitely depend to some degree on the price policy of the European Pyrites Corporation. Owned jointly by the Rio Tinto marketing combine (an organization by which the Rio Tinto mines in 1928 obtained a marketing control of Tharsis, Orkla, Cyprus, and Mason and Barry, thus uniting Spanish, Norwegian, Cyprus, and Portuguese producers) and the *Metallgesellschaft,* the corporation will find that any substan-

tial increase in price will cause even the sulfuric acid concerns on the Atlantic seaboard, except the fertilizer outlets controlled by Rio Tinto, of course, to discontinue using pyrites. Assuming that the price policy will remain one of seeking stability rather than of trying to charge "what the traffic will bear," as the market for the by-product metals in the pyrites cinder improves, thus reducing the net cost of the raw material, the concerns which still have substantial investment in pyrites-burning equipment will continue to import it. Otherwise even the import of pyrites, except the by-product concentrates from Canada, may become virtually negligible.

On the other hand, contrast the amazing development of the sulfur industry. Marketed production, after fluctuating around the 300,000-ton level before the war, jumped from 293,803 tons in 1915 to 766,835 tons in 1916 and again to 1,120,373 tons in 1917. By 1920 the war total had been exceeded and by 1930 more than doubled, reaching the amazing figure then of 2,558,981 tons, despite the fact that in 1924 the original deposit of the Union Sulphur Company in Louisiana, after producing over 10,000,000 tons, had been exhausted.

At present nearly 85 per cent of domestic sulfur production comes from Texas, and the rest, except for four thousand tons (produced by six operators in California, five of them in Inyo County), from Louisiana. New methods of geophysical prospecting for oil have incidentally uncovered dozens of sulfur deposits in the Gulf Coastal region. Sixty-four prospective domes were thus discovered in the four-year period from 1924 to 1928, thirty of them in the one year 1928,[20] some of which have been developed into singularly productive mines. In 1929 the Texas Gulf Sulphur Company opened a well at

[20] United States Department of Commerce, Bureau of Mines, *Mineral Resources of the United States 1928* (2 vols., Washington, D.C., 1929), Vol. II (*Non-Metals*), p. 58.

Boling Dome, Newgulf, Texas, which became the world's largest producer. In 1934 five mines were operating in Texas, two belonging to the Texas Gulf Sulphur Company at Boling Dome and Long Point Dome producing 845,428 tons, two belonging to the Freeport Sulphur Company at Bryan Mound and Hoskins Mound in Brazoria County producing 297,555 tons, and one belonging to the Duval Texas Sulphur Company at Pelangana Dome, Benavides, Texas, producing 44,695 tons. There were two domes operating in Louisiana, one belonging to the Freeport Sulphur Company at Grande Ecaille in Plaquemines Parish, the other belonging to the Jefferson Lake Oil Company, Inc., at Lake Peignieur in Iberia Parish. The two of them produced 229,830 tons of sulfur in 1934.[21]

Thus at the present time sulfur is being produced in amounts formerly undreamed of, by methods representing the acme of efficiency and large-scale, continuous operation. The deposits are not only large but are near tidewater, so that shipping charges to large centers of consumption in New York, New Jersey, and Pennsylvania are not prohibitive.

At the present time the United States is not only the leading producer and consumer of sulfur but the chief exporter. Exports jumped from 37,271 tons in 1915 to 128,755 tons in 1916, to 224,712 tons in 1919, to 477,450 tons in 1920, and again to 855,183 tons in 1929. The chief market is Canada, which in 1934 took 28.7 per cent of the total, France taking 14.2 per cent. The price at which sulfur has been sold has remained virtually unchanged at $18 a ton f.o.b. mines, spot prices for car lots being $1.00 to $3.00 higher, and those for sulfur exported being given as $22 per ton f.a.s. Atlantic ports. Even the imposition of a severance tax of 55 cents a ton by the state of Texas in 1930, followed in Louisi-

[21] Data for this paragraph obtained from United States Department of the Interior, Bureau of Mines, *Minerals Yearbook 1935* (Washington, D.C., 1935), pp. 1011–20.

ana in 1934 by one of 27 cents a ton which was later raised to 60 cents a ton, has not altered price quotations. The depression has similarly had no effect. This remarkable stability of prices is also present in the case of pyrites, which for the Spanish imported ore has for years normally stood c.i.f. New York at 13 cents a unit or $6.50 a ton of 50 per cent sulfur, from which, when the sum of $3.50 to $3.74 is deducted for freight, there is left a net price of $2.75 or $3.00 for the European combination.

Immediately after the World War when the Texas Gulf Sulphur Company opened the property at Big Hill, Texas, which the government had helped it to develop, there was, however, a brief period of price competition. The annual average price (as reported by the Bureau of Labor Statistics in its publications on wholesale prices) went down from $23.84 in 1920 to $15.90 in 1921 and to $14.00 in 1923. There followed a twofold result. In 1922 a Sulphur Export Corporation was formed under the provisions of the Webb-Pomerene Act which permitted combinations designed to promote exports. This has served effectively ever since, preventing price competition not only in the foreign market but also in the home market. In 1926 the price of sulfur was re-established at $22 a ton for export and $18 at home, where it has remained ever since.

The second effect was even more striking. For the fourth time sulfur became the subject of international negotiations. The low prices of 1921 and 1922 caused Sicilian production to dwindle to 135,000 tons in 1922 from levels three times as high before the World War. While a part of this decline was undoubtedly due to higher costs because of the deepening of the mines, partial exhaustion of the ore, inundations, and so on, no small part represented the invasion of export markets by American competition.

In 1921 this competition became so severe that Italy, even,

had to forbid imports of sulfur. Once more the industry seemed to be faced with extinction. Revolution was again in ferment.

Fortunately it was possible in 1923 to form a gentlemen's agreement between the American Sulphur Export Association and the *Consorzio* to hold good until September 30, 1926, whereby the North American market was reserved for the Texas companies, Italy was reserved for Sicily, and the rest of the world was divided proportionately between the two syndicates with the provision that Sicily might sell to any country a maximum of 65,000 tons for sulfuric acid manufacture. The Consortium set up a Central Sales Bureau in London to exchange information and statistics, to arbitrate quota disputes, and so forth. Sicily increased her exports from 110,000 tons in 1923 to the allowable 210,000 tons per annum in 1924.

By mutual consent the agreement has at intervals been extended, the most recent extension dating from July 1934, when the American interests again permitted a *modus vivendi* to be brought into existence for the Sicilian and the Continental Italian producers. According to it annual exports up to 480,000 tons are to be divided equally, and of sales over this tonnage 75 per cent is allotted to American sulfur and 25 per cent to the Italian product. Minimum sales figures were set at current levels, the Italian government guaranteeing to producers a minimum price of 264 lire per ton for good sulfur and making certain additional tax reductions.[22]

SULFUR VERSUS PYRITES AT PRESENT

Estimates of the kind and amounts of raw material used by the sulfuric acid industry have been brought together in

[22] Data for this paragraph taken from United States Department of the Interior, Bureau of Mines, *Minerals Yearbook 1935* (Washington, D.C., 1935), p. 1022.

Table 20 below. A complete cycle has taken place, the sulfuric acid industry being, so far as the use of sulfur is concerned, back in the position of the 'eighties. And, just as in the 'eighties, the practice here differs considerably from that in other parts of the world, though not quite so much so as

TABLE 20

ESTIMATED PERCENTAGE OF SULFURIC ACID MADE FROM PRIMARY RAW MATERIALS, 1885–1934*

Year	From Brimstone	From Pyrites		By-Products from Zinc and Copper Ores
		Domestic	Foreign	
1885	85	13	1	1
1891	80	10	9	1
1895	75	7	17	1
1901	16	26	55	3
1909	2	20	64	12
1914	3	17	60	20
1919	48	15	21	16
1925	68	6	13	13
1929	69	7	10	14
1934	67	10	12	11

* Estimated from data of sulfur and pyrites consumption given in Tables 21–23; from data on by-product acid production issued yearly by the Bureau of Mines, given in the next chapter; from Bureau of the Census reports on materials consumed by the sulfuric acid industry; and from data on various strengths of acid, especially oleum, produced.

then. Great Britain in 1928, for example, obtained 44 per cent of her sulfuric acid from pyrites, 25 per cent from spent oxide from gas works, 10 per cent from zinc concentrates, and only 21 per cent from sulfur. In Germany, 90 per cent is produced from pyrites and zinc blende and less than 10 per cent from sulfur.[23] Practice in other countries varies between that in Germany and that in the United States.

[23] United States Department of Commerce, Bureau of Mines, *Mineral Resources of the United States 1929* (2 vols., Washington, D.C., 1930), Vol. II (*Non-Metals*), p. 184.

TABLE 21

Imports of Brimstone, 1821–1865*

Year	Quantity[a]	Value	Year	Quantity[a]	Value
1821 .		$ 29,446	1841 .		$113,454
1822 .		59,528	1842 .		84,422
1823 .		22,684	1843 .		22,239
1824 .		4,362	1844 .		75,124
1825 .		26,667	1845 .		108,619
1826 .		46,077	1846 .		91,334
1827 .		36,511	1847 .		193,521
1828 .		29,484	1855 .	11,055	204,123
1829 .		14,425	1856 .	8,371	163,500
1830 .		17,240	1857 .	7,185	152,330
1831 .		36,634	1858 .	8,442	249,317
1832 .		61,177	1859 .	11,728	324,176
1833 .		21,160	1860 .	15,502	394,896
1834 .		55,876	1861 .	13,277	369,329
1835 .		167,155	1862 .	9,601	315,658
1836 .		130,017	1863 .	14,968	450,505
1837 .		69,321	1864 .	12,028	288,019
1838 .		42,214	1865 .	9,465	257,618
1839 .		101,164			
1840 .		65,751			

* Data for the imports of sulfur prior to 1866 are taken from the letters of the Secretary of the Treasury to the Speaker of the House of Representatives and to the President of the Senate of the United States on the Commerce and Navigation of the United States.

[a] Long tons.

TABLE 22

Production, Imports, Exports, and Consumption of Sulfur, 1867–1934

Year	Marketed Production[a]		Imports[b]		Exports[c]		Consumption[d]
	Quantity[e]	Value	Quantity[e]	Value	Quantity[e]	Value	Tons
1867........	......	......	24,544	$ 620,373	......	......	24,544
1868........	......	......	18,151	446,547	......	......	18,151
1869........	......	......	23,590	678,642	......	......	23,590
1870........	......	......	27,380	819,408	......	......	27,380
1871........	......	......	36,131	1,212,448	......	......	36,131
1872........	......	......	25,380	764,798	......	......	25,380
1873........	......	......	45,533	1,301,000	......	......	45,533
1874........	......	......	40,990	1,260,491	......	......	40,990

TABLE 22—(*Continued*)

Year	Marketed Production[a]		Imports[b]		Exports[c]		Consumption[d]
	Quantity[e]	Value	Quantity[e]	Value	Quantity[e]	Value	Tons
1875...				$1,259,472			39,683
1876...			46,435	1,475,250			
1877...			42,963	1,242,888			42,963
1878...			48,102	1,179,769			48,102
1879...			70,370	1,575,533			70,370
1880...	536	21,000	87,837	2,024,121			88,373
1881...	536	21,000	105,097	2,713,485			105,633
1882...	536	21,000	97,504	2,627,402			
1883...	893	27,000	94,540	2,288,946			95,433
1884...	446	12,000	105,112	2,242,697			105,558
1885...		17,875	96,839	1,941,943			97,477
1886...	2,232	75,000	117,538	2,237,989			119,770
1887...	2,679	100,000		1,688,360			99,561
1888...				1,581,583			98,252
1889...	402	7,850		2,068,208			136,335
1890...			162,674	2,762,953			162,674
1891...	1,071	39,600	116,971	2,675,192			118,042
1892...	2,400	80,640	100,938	2,189,481			103,338
1893...	1,071	42,000	105,539	1,903,198			106,610
1894...	446	20,000	125,241	1,703,265			125,687
1895...	1,607	42,000	121,286	1,546,481			
1896...	4,696	87,200	138,168	1,967,454			142,864
1897...	2,031	45,590	136,563				138,594
1898...	1,071		151,225	2,891,767			152,296
1899...	4,313	107,500	140,182	2,484,801			144,495
1900...	3,147	88,100	166,825	2,917,172			169,972
1901...			174,160	3,256,990			181,026
1902...	7,443		170,601	3,334,002			178,044
1903...	35,098		188,990	3,649,756			224,088
1904...	127,292		127,996	2,462,360	3,000		252,288
1905...	181,677	3,706,560	82,961	1,528,136	6,722	$ 132,716	257,916
1906...	294,153	5,096,678	72,404	1,282,873	17,853	357,548	348,704
1907...	293,106	5,142,850	20,399	355,944	18,077	367,230	
1908...	369,444	6,668,215	19,620	318,577		785,335	350,542
1909...	258,203	4,782,066	28,800	492,962	31,525	635,527	255,478
1910...	250,919	4,522,112		558,611	45,595	864,808	236,157
1911...	253,795	4,573,000	29,144		17,269	326,735	265,670
1912...	305,390	5,289,000	29,927	583,974	57,736	1,076,414	277,581
1913...		5,617,000	22,605	448,564		1,599,761	252,717
1914...	341,985	6,214,000	26,135	447,937	98,153	1,807,334	369,967
1915...		4,959,000	24,647	405,990	37,271	724,679	281,179
1916...		12,246,000	21,289	358,416	128,755	2,505,857	
1917...	1,120,378	23,987,000	973	20,176	152,763	3,500,819	
1918...	1,266,709	27,868,000	55	1,692	131,092		1,135,672
1919...	678,257	10,252,000	77	1,997	224,712	6,325,552	

TABLE 22—(*Concluded*)

Year	Marketed Production[a]		Imports[b]		Exports[c]		Consumption[d]
	Quantity[e]	Value	Quantity[e]	Value	Quantity[e]	Value	Tons
1920........	1,517,625	$30,000,000	44	$ 1,722	477,450	$ 8,994,350	1,040,219
1921........	954,344	17,000,000	4	226	285,762	4,524,768	668,586
1922........	1,343,624	22,000,000	167	12,549	487,969	7,209,767	855,822
1923........	1,618,841	26,000,000	465	21,535	474,475	7,216,107	1,144,831
1924........	1,537,345	25,000,000	1,005	40,293	482,114	7,792,854	1,056,236
1925........	1,858,003	29,000,000	100	4,411	629,401	11,000,235	1,228,702
1926........	2,072,657	37,300,000	48	1,052	576,966	10,918,394	1,495,809
1927........	2,072,109	38,300,000	3,384	34,487	789,274	16,254,227	1,286,219
1928........	2,082,924	37,500,000	4,787	21,320	685,051	14,345,075	1,402,660
1929........	2,437,238	43,800,000	1,163	6,616	855,183	17,628,813	1,583,218
1930........	1,989,917	35,800,000	29	1,523	593,312	12,416,233	1,396,634
1931........	1,376,526	24,800,000	......	......	407,586	8,837,268	968,940
1932........	1,108,852	20,000,000	......	......	352,610	7,178,566	756,242
1933........	1,637,368	29,500,000	4,773	67,432	522,515	9,877,879	1,119,626
1934........	1,613,838	28,900,000	5,839	76,631	503,312	9,294,228	1,116,365

[a] Data for "marketed production" are taken from the successive issues of the *Mineral Resources of the United States* published by the Department of the Interior, United States Geological Survey, from 1882 until 1923, by the Department of Commerce, Bureau of Mines, until 1931, and by the Department of the Interior, Bureau of Mines, since that time. Beginning with issue of 1932–1933 the name of the publication has been changed to *Minerals Yearbook*.

[b] Taken from same source as "marketed production." Data for the years from 1867 to 1887, inclusive, apply to the fiscal year ending June 30.

[c] Data for exports up to 1910 are taken from successive issues of *Foreign Commerce and Navigation of the United States*, published from 1867 to 1892, inclusive, by the Chief of the Bureau of Statistics on the Commerce and Navigation of the United States, from 1893 to 1903, inclusive, by Bureau of Statistics in the Treasury Department, from 1904 to 1911, inclusive, in the Department of Commerce by the Bureau of Statistics, and since 1911 by the Bureau of Foreign and Domestic Commerce.

[d] Consumption figures computed as equal to production plus imports minus exports.

[e] Quantity figures in long tons.

The competitive position of sulfur is for the present extraordinarily strong. While it cannot supplant the sulfur in fumes from the roasting of zinc and copper ores and that from concentrates, it will probably continue to displace other pyrites, both domestic and foreign, except where there are financial or other controls of the mines by sulfuric acid producers and similar control of consuming outlets by pyrites producers. If the many other uses for sulfur should begin to require large amounts of it—whether to make sulfite wood

TABLE 23

PRODUCTION AND IMPORTS OF PYRITES, 1882–1934*

Year	Production		Imports		Consumption[a]
	Quantity	Value	Quantity	Value	Tons
1882	12,000	$ 72,000			12,000
1883	25,000	137,500			25,000
1884	35,000	175,000	16,710	$ 50,632	51,710
1885	49,000	220,500	6,078	18,577	55,078
1886	55,000	220,000	1,605	9,771	56,605
1887	50,500	210,100	16,578	49,661	67,078
1888	54,331	167,658			54,331
1889	104,950	202,119			104,950
1890	111,836	273,745			111,836
1891	119,320	338,880	100,648	392,141	219,968
1892	122,963	305,191	152,359	587,980	275,322
1893	84,870	256,552	194,934	721,699	279,804
1894	105,940	363,134	163,546	590,905	269,486
1895	99,549	322,845	190,435	673,812	289,984
1896	115,483	320,163	200,168	648,396	315,651
1897	143,201	391,541	259,546	747,419	302,747
1898	193,364	593,801	252,773	717,813	446,137
1899	174,734	543,249	269,868	1,077,061	444,602
1900	204,615	749,991	322,484	1,055,121	527,099
1901	241,691	1,257,879	403,706	1,415,149	645,397
1902	207,874	947,089	420,410	1,636,451	628,284
1903	233,127	1,109,818	440,363	1,650,852	673,490
1904	207,081	814,808	422,720	1,533,997	629,801
1905	253,000	938,492	511,446	1,744,379	764,446
1906	261,422	931,305	598,078	2,148,588	859,500
1907	247,387	794,949	627,985	2,581,787	875,372
1908	222,598	857,113	668,117	2,644,339	890,715
1909	247,070	1,028,157	688,843	2,428,530	935,913
1910	241,612	977,978	803,551	2,748,647	1,045,163
1911	301,458	1,164,871	1,006,310	3,788,803	1,307,768
1912	350,928	1,334,259	970,785	3,841,683	1,321,713
1913	341,338	1,286,084	850,592	3,611,137	1,191,930
1914	336,662	1,283,346	1,026,617	4,797,326	1,363,279
1915	394,124	1,674,933	964,634	4,817,977	1,358,758
1916	439,132	2,038,002	1,244,662	6,728,318	1,683,794
1917	482,662	2,593,035	967,340	5,981,457	1,450,002
1918	464,494	2,644,515	496,782	2,741,676	961,286
1919	420,647	2,558,172	388,973	2,176,565	809,620

TABLE 23—(*Continued*)

Year	Production		Imports		Consumption[a]
	Quantity	Value	Quantity	Value	Tons
1920	310,777	$1,596,961	332,606	$1,660,832	643,383
1921	157,118	711,432	216,229	818,852	373,347
1922	169,043	671,241	279,445	1,199,076	444,488
1923	181,628	661,000	263,695	1,254,389	445,323
1924	160,096	645,262	246,737	598,544	406,833
1925	170,081	650,448	276,385	773,925	446,466
1926	166,559	616,668	366,151	856,981	532,710
1927	215,786	804,006	250,794	647,512	466,580
1928	312,815	1,081,758	458,264	1,140,736	771,079
1929	333,465	1,250,141	514,336	1,507,648	847,801
1930	347,512	1,028,680	368,114	1,037,017	715,626
1931	330,848	974,820	352,066	1,496,197	682,914
1932	186,485	492,043	253,248	691,144	439,733
1933	284,311	769,942	374,417	1,132,137	658,728
1934	432,524	1,216,363	366,315	1,245,660	798,839

* Source of data same as indicated in footnote *a* to Table 22 preceding.
[a] Production plus imports.

pulp, or insecticides, or explosives, or dyes, or rubber—sulfur producers may readily decide to relinquish their hold on the sulfuric acid outlet. Within ten or twenty years the ideals of conservation of natural resources may well suggest an increased use of pyrites, the more so since the recent development of vanadium catalysts makes it possible to produce contact acid of the desired high strengths from raw gases.

From the social point of view the rapid depletion of a limited supply of so essential a raw material as sulfur is a matter for serious thought, especially when so much of it is wasted by copper, lead, and zinc smelters in their blast furnace and roasting oven gases. The speedy perfection of technological and legal measures which will utilize as fully as possible all the by-product sources of supply, including the marcasite from the coal fields, the sulfur in certain petroleums, and that from manufactured fuel gases, would seem to be a worthy goal for research and social action.

VII. Interindustry Competition

One of the most important forms of competition in the chemical industry, that of interindustry competition, appears not only in consumption but also in production. Competition for the consumer's dollar is, of course, a familiar fact in almost every industry. But, as has already been mentioned, however many substitutes there may be for such an article as, for example, lumber, the commodity itself (to be sure in a variety of grades) comes from lumber mills. Similarly sugar is produced by sugar factories, cotton goods by cotton mills, and so on, each such industry exhibiting more or less similar techniques, similar production and sales problems, and similar competitive relationships. But in the chemical industry an article may come from widely different industries, using different raw materials, with different joint or by-products, and different production requirements and sales stimuli.

The sulfuric acid business is such an industry. As is shown on Figure 9 and in Table 24, since 1919 only about 30 to 35 per cent of the total production comes from producers who have to get their bread and butter from making and selling sulfuric, nitric, and mixed acids. From 20 to 30 per cent is put on the market by a conglomerate of industries whose primary products are lumped together by governmental censuses as "chemicals not elsewhere classified." Another 25 to 30 per cent is produced by fertilizer plants, and the remainder is obtained from a variety of industrial processes such as copper, lead, and zinc smelting, explosives manufacture, by-product coke-oven operations, and reclaimed or secondary acid recovery practiced especially by petroleum refineries. In each of these types of enterprise sulfuric acid is but one of a varying composite of intermediary and finished products.

COMPETITION IN PRODUCTION

The amounts produced by the various industries are shown for the period from 1899 to 1935 in Table 24, below.

Two highly significant trends are evident. The first is the growing tendency for the production of sulfuric acid to be spread among a number of industries. In 1899 only two

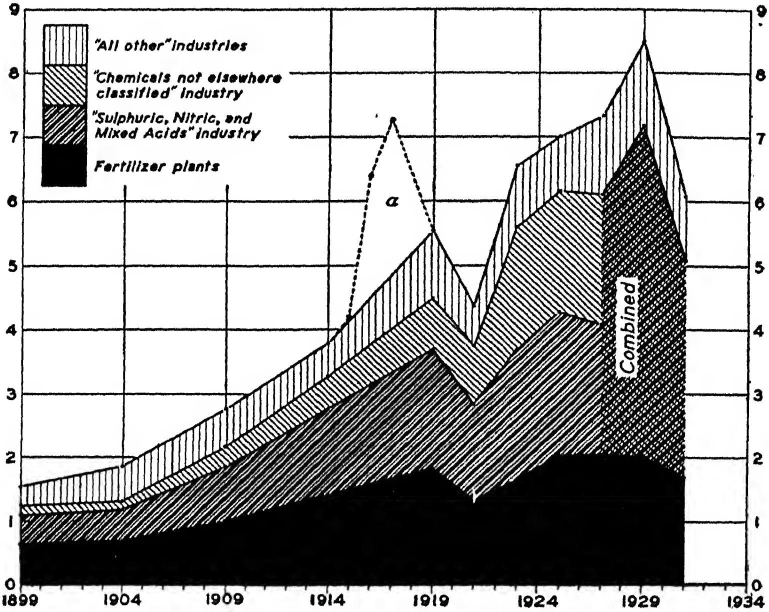


FIG. 9.—Production of sulfuric acid by industries, 1899–1931 (50° Bé. basis). For sources of data, see Table 24. Bulge (*a*) due mostly to production by manufacturers of explosives.

industries made it in any large quantity: one, the fertilizer industry, producing almost exclusively for its own use, sold scarcely more than ten per cent of its output; the other, the sulfuric, nitric, and mixed acids industry, was then almost the only source of commercial supply. The business was still relatively simple, quite similar in this regard to that of non-chemical industries. Contrast the situation in 1927. No less

TABLE 24

Production of Sulfuric Acid, by Industries, 1899–1935

(50° Bé. Basis)*

Year	Total		By Sulfuric, Nitric, and Mixed Acids Industry		By "Chemicals Not Elsewhere Classified"		By Fertilizer Industry		Explosives		Reclaimed		Zinc Smelters[a]	Copper Smelters
	Tons	Percentage for Sale	Tons	Percentage for Sale	Tons	Percentage for Sale	Tons	Percentage for Sale	Tons	Percentage for Sale	Tons	Percentage for Sale	Tons (60° Bé. Acid)	Tons (60° Bé. Acid)
1899........	1,548,123	51	452,942[b]	..	135,433[b]	..	642,938	11	32,366	..	.....[c]	..	58,828	......
1904........	1,869,436	48	467,614[b]	..	139,612[b]	..	717,406	3	30,994	..	.....[c]	..	94,032	......
1909........	2,748,527	54	855,191[b]	..	300,000[d]	..	995,384	15	42,555	..	7,069	..	160,000[d]	150,000[d]
1914........	3,790,000	62	1,359,183[b]	..	500,488[b]	..	1,405,768	9	31,207	..	136,360	..	411,711	348,727
1919........	5,552,581	60	1,898,778	88	775,499	68	1,812,084	16	85,228	50	473,555	20	502,324	364,991
1921........	4,369,941	60	1,523,178	91	905,468	69	1,321,844	13	94,930	31	200,861	84	286,826	285,444
1923........	6,555,517	66	2,049,293	91	1,926,142	74	1,631,217	16	146,938	27	588,668	29	384,489	401,300
1925........	7,004,112	67	2,165,085	90	1,867,163	72	2,008,418	33	162,057	30	768,765	27	480,378	392,652
1927........	7,335,795	68	2,035,800	93	2,035,658	67	2,045,344	38	138,219	23	757,107	25	472,823	416,599
1929........	8,491,114	68	5,157,835 tons, 80% for sale				2,002,105	31	133,656	34	980,626	39	627,018	588,325
1931........	6,085,242	69	3,398,555 tons, 84% for sale				1,685,950	35	75,860	32	880,323	40	426,618	436,111
1935........	6,462,212	69	......[a]		......[a]		.......[a]	..	.....[a]	..	......[a]	..	443,476	160,151[e]

* Tonnage figures from the Bureau of the Census reports on "Chemicals and Allied Products" in the censuses of manufactures for the years indicated; percentage figures have been computed from data of product for sale in Table 25.

Figures of the separate industries do not add to the number given in the total because the production of sulfuric acid by petroleum refineries, by mucilage and paste manufacturers, by coke-oven operators, etc., is omitted. Moreover, reclaimed acid is not added into the total. Finally, acid from zinc and copper smelters is given on 60° Bé. basis.

[a] Amount made from zinc blende only. [b] Product for sale probably represents about 90 per cent of total production.
[c] No data. [d] Estimated. [e] Excludes acid made by the Anaconda Mining Company and acid made from pyrites concentrates in Tennessee.

than eight industries are producing sulfuric acid in large quantities and a half-dozen others in smaller amounts. In two of them, the "chemicals not elsewhere classified" industry and the fertilizer industry, the amount produced is equal to that put out by those for whom sulfuric acid is the main business. Yet the former sells only two-thirds of its product and the latter only one-third, while the regular industry must find a market for 13 out of every 14 tons. Moreover, competition with industries in which sulfuric acid is only a side line is made more acute by competition with industries which more or less dump it as a nuisance—the zinc and copper smelters, and the gigantic petroleum industry, among others, producing in 1929 over two million tons of 60° Bé. and reclaimed acid, an amount larger than that of the old-line industry itself. At nearly every turn competitors responding to different sets of economic forces complicate and make difficult the carrying out of production programs and the making of plans and forecasts.

The second trend revealed by the table is the tendency for the percentages produced for sale to be larger and larger. This is not only true of the aggregate but is strikingly characteristic of the output of the fertilizer and reclaimed acid industries. The reasons will become clear when the multiplication of the uses of sulfuric acid is explained in chapter xii. The trend also reflects the effect of improvement in modes of transport and the increasing propensity of chemical establishments in modern times to multiply the bases of their business in order to secure stability through diversification.

COMPETITION IN SALES

The growing tendency for consumers of sulfuric acid to make more of it than they need for themselves shows itself particularly clearly in the sales figures. Notice in Table 25 the manner in which the share of the market enjoyed by the sulfuric, nitric, and mixed acids industry went down from

59 per cent in 1899 to 38 per cent in 1927. Even when the sales figure of the old-line industry is added to that of "chemicals not elsewhere classified," the proportion of the total acid sold in 1931 (67 per cent) is still somewhat less than the combined figure in 1899 (76 per cent).

This result is not wholly or even primarily due to loss in competitive vigor or to the growing strength of other industries. In large part it is due to a change in business policy by sulfuric acid producers themselves. For reasons that will be explained in detail in chapter ix, they have seen best to branch out into new lines of manufacture, concentrating and risking less upon sulfuric acid, being content to lose out somewhat in their primary market, in order to make and sell other things, among them those that consume sulfuric acid, thus more fully coping with competition in derivative or secondary markets.

This reaching forward and sideward into the manufacture and sale of chemicals nearer the consumer has been paralleled by integration backward to the manufacture of sulfuric acid by producers of finished chemicals such as dyestuffs and petroleum products. With the rapid growth of these industries, sulfuric acid began to be consumed by individual businesses in large quantities, quantities large enough to make a plant of their own economically feasible. Difficulties and uncertainties incidental to shipping are thus avoided, operations of the businesses as a whole can be more closely dovetailed, and greater bargaining independence is obtained.

Coupled with the efforts of consuming industries to become self-sufficient is their attempt to diversify. Table 25 indicates that while the amount of sulfuric acid sold by the regular sulfuric acid industry increased fourfold between 1899 and 1927, that of the "chemicals not elsewhere classified" industry and of fertilizer manufacturers increased tenfold, and the output of zinc smelters increased eightfold. In the mean-

TABLE 25

SULFURIC ACID SOLD, BY INDUSTRIES, 1899–1935
(Thousands of Tons, 50° Bé. Basis) *

Year	Aggregate Sales (Actual Tonnage Figures)	By Sulfuric, Nitric, and Mixed Acids Industry		By "Chemicals Not Elsewhere Classified" Industry		By Fertilizer Industry		By Explosives Industry		By Zinc Blende Roasting Plants from Zinc Blende (60° Bé. Basis)		By Copper Smelters		By Petroleum Refiners Sold Reclaimed	Reclaimed
		Tons	Percentage of Total	Tons	Percentage of Total	Tons	Percentage of Total	Tons	Percentage of Total	Tons	Percentage of Total	Tons	Percentage of Total	Tons	Tons
1899	782,768	452	58	135	17	71	9	..[a]	..	58 tons[b], 7% for sale				...[a]	...[a]
1904	900,991	467	52	139	15	24	3	..[a]	..	94 tons[b], 10% for sale				165	...[a]
1909	1,479,200	855	58	300[c]	20	153	10	..[a]	..	160[bc]	11	150[bc]	..	133	7
1914	2,338,284	1,359	58	500	21	129	5	..	..	412[b]	18	349[b]	..	90	136
1919	3,331,362	1,685	51	524	16	282	8	42	1	502	15	365[b]	11	136	95
1921	2,603,532	1,380	53	623	24	176	7	29	1	286	11	285[b]	11	111	168
1923	4,344,698	1,875	43	1,427	33	265	6	39	1	334	9	401[b]	9	64	170
1925	4,700,197	1,935	41	1,348	29	663	14	48	1	480[b]	10	393[b]	8	67	210
1927	4,971,583	1,902	38	1,364	27	775	16	32	1	473[b]	10	417[b]	8	...[a]	191
1929	5,816,165	4,140 tons, 71% for sale				629	11	45	1	627[b]	11	588[b]	10	...[a]	381
1931	4,229,753	2,845 tons, 67% for sale				583	14	24	1	427[b]	10	436[b]	10	...[a]	356
1933	3,847,889	......[a]		......[a]		...[a]	..	..[a]	..	(See Table 29)		...	..	...[a]	...[a]
1935	4,470,469					...[a]	..	..[a]	..	...	..	...	..	...[a]	...[a]

* Tonnage figures from Bureau of the Census reports on "Chemicals and Allied Products" in census of manufactures for the years indicated; percentages computed.

Total across the table sometimes adds up to more than 100 per cent because figures are rounded off to nearest percentage and because there is a small amount of duplication due to resale by large users, such as fertilizer plants, of a part of the acid sold, e.g., by smelters. No percentages were computed for the reclaimed acid because it is obviously 100 per cent resold.

[a] No data. [b] Total produced. No separate figures available for amounts consumed where made or amounts for sale. [c] Estimated.

time the output and sales of copper smelters grew from almost nothing to more than half a million tons in 1929.

The market has thus become a scramble between by-product acid; reclaimed acid; acid the overhead and administrative expenses of which are covered in whole or in part by proceeds from the sale of fertilizers, explosives, or chemicals; and sulfuric acid produced for its own sake as a main product wholly paying its own way.

COMPETITION IN PRICE

Price competition in the sulfuric acid industry is marked by unusual stability of quotations in any given market but considerable diversity as between markets. Since the acid is hard to transport and bulky, and inasmuch as sulfur is easy to ship and one ton makes from four and a quarter to four and three-quarters tons of sulfuric acid, points of local demand remote from industrial centers are likely to offer profitable opportunities for establishing small, even if inefficient, plants, each with a modified monopoly control of price in a restricted area. The net value per ton realized accordingly differs considerably between areas and between industries.

In Table 26 a comparison is made in dollar terms of the sales of the various sulfuric acid producing industries. While reinforcing the facts shown by comparing tonnages, the figures here present some interesting modifications. The importance of the reclaimed acid and by-product acid from copper smelters is considerably diminished, that of by-product acid from zinc smelters is increased, and the old-line industry shows itself much stronger. In other words, the tonnage market it has partly relinquished is that for low-grade, low-priced acid.

Even more striking is the difference in net average prices realized per ton. Lowest on the list is the figure for reclaimed acid, being over three dollars per ton lower than the general

TABLE 26

VALUE OF SULFURIC ACID SOLD AND AVERAGE PRICE REALIZED PER TON, BY INDUSTRIES, 1899–1935

(Sales Figures in Thousands of Dollars, Average Price Realized to Nearest Ten-cent Figure)*

Year	Grand Total of Sales in Dollars	Average Price Realized	Sulfuric, Nitric, and Mixed Acids Industry		"Chemicals"		Fertilizer		Explosives		Petroleum Refineries		Reclaimed Acid		Zinc		Copper	
			Sales	Dollars per Ton	Sales	Dollars per Ton	Sales	Dollars per Ton	Sales	Dollars per Ton	Sales	Dollars per Ton	Sales	Dollars per Ton	Sales	Dollars per Ton	Sales	Dollars per Ton
1899	7,305,444	9.30	4,071	9.00	....[a]	....	438	6.20	...[a]	....	...[a]	....	...	....	424		7.30	
1904	7,942,211	8.80	4,286	9.20	....[a]	....	195	8.10	...[a]	....	400	2.40	...	....	576		6.10	
1909	10,103,425	6.80	5,629	6.60	....[a]	....	923	6.00	...[a]	....	215	1.60	63	....	....[a]	....	....[a]	....
1914	15,395,133	6.60	9,044	6.70	3,773	7.50	769	6.00	...[a]	....	491	5.50	519	3.80	2,974[b]	7.20	2,216	6.30
1919	35,932,605	10.80	18,113	10.70	6,461	12.30	3,330	11.80	537	12.80	687	5.10	803	8.50	6,165[b]	12.30	2,084	5.70
1921	27,417,905	10.50	14,406	10.40	7,228	11.60	1,882	10.70	337	11.60	605	5.50	1,634	9.70	3,404[b]	11.90	2,451	8.60
1923	38,274,540	8.80	17,140	9.10	13,430	9.40	2,006	7.60	380	9.70	392	6.10	1,479	8.70	3,375[b]	8.80	2,834	7.10
1925	38,230,184	8.10	16,020	8.30	11,613	8.60	4,812	7.30	414	8.60	388	5.80	1,479	7.00	4,493[b]	9.40	2,277	5.80
1927	42,885,573	8.60	16,804	8.80	12,881	9.40	6,158	7.90	266	8.30	...[a]	....	1,089	5.70	4,775[b]	10.10	2,490	6.00
1929	45,573,245	7.80	32,736			7.90	4,981	7.90	438	9.70	...[a]	....	1,389	3.60	6,311[b]	10.10	3,333	5.70
1931	33,074,957	7.80	24,024			8.40	3,869	6.60	193	8.00	...[a]	....	1,320	3.70	3,746[b]	8.80	....[a]	....
1933	26,482,063	6.90	.....[a]			....	....[a]	....	...[a]	....	...[a]	....	...[a]	....	2,677[b]	7.50	....[a]	....
1935	31,907,806	7.10	.....[a]			....	....[a]	....	...[a]	....	...[a]	....	...[a]	....	....[a]	....	....[a]	....

* Sales figures from Bureau of the Census reports on "Chemicals and Allied Products" in censuses of manufactures for the respective years; the figures for average value realized per ton were computed.

[a] No data.

[b] Value of production of acid from zinc blende only. The total amount of acid sold runs sometimes twice as high—see Table 19, line 6.

average during periods of depression but even in periods of prosperity being somewhat lower. In 1929 and 1931 it sold at less than one-half the average. Next lowest is the figure for the acid from copper smelters, despite the fact that it is 60° Bé. acid and should receive a price some 25 per cent higher, as does the acid from zinc smelters. In years of low activity for copper, that is, years of depression, the amount of difference narrows down to less than a dollar, but in years of high activity in copper mining, particularly in 1919 and 1925, the difference widens to three, four, or even more than five dollars. This is, of course, typical joint-cost behavior.

On the other hand, the acid sold by the explosives and the "chemicals" industries usually commands a premium, owing in part to the fact that more of the higher strength acids are sold (both industries make and require a good deal of oleum) and in part to flexibility in production so that acid is usually made and sold for the profit in it. Thus the differences in prices are due to local limitations of the special market accessible to each industry, to differences in strengths of acids sold, to differences in localities in which the several industries are situated, and to differences in forces impelling or compelling production.

SULFURIC ACID AS SUBSIDIARY PRODUCT

Since the beginning of the century, sulfuric acid has been a subsidiary product in most of the establishments producing it. In 1899, 93 of the 127 establishments listed by the census were engaged primarily in the manufacture of other products. In 1904 the number was 115 out of 147; in 1909, 141 out of 183; in 1914, 162 out of 194; in 1919, 177 out of 216; in 1923, 148 out of 185; and in 1927, 146 out of 181. The number of establishments whose primary product was sulfuric acid remained roughly the same during the last forty years, being 34 in 1899, 42 in 1909, 39 in 1919, and 35 in

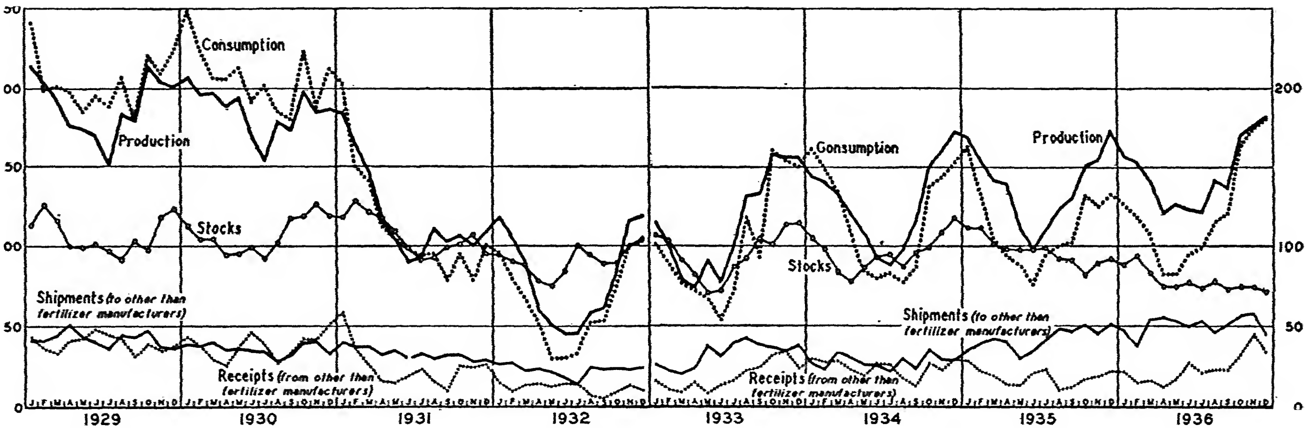


FIG. 10.—Sulfuric acid in the fertilizer industry, 1929–1936. For source of data, see Table 27.

1927. (The discussion of the products other than sulfuric acid which are put out by these establishments is deferred until chapter ix.)

Most numerous among the establishments producing sulfuric acid as a subsidiary product are those whose primary product is fertilizers, especially those producing superphosphates. By treating phosphate rock (or bones) ton for ton with sulfuric acid, an acid phosphate is formed which when mixed with ammoniates, potash, or both makes the various grades of ammoniated superphosphates or complete fertilizer that are sold to the farmers. Most of the demand exists in states with well-cropped cotton lands. In 1899, of 422 fertilizer-producing works there were 76 which made sulfuric acid, 20 of them not making enough for their own use and supplying their deficiency from other sources. In addition there were 76 plants that made superphosphates and purchased all the needed acid. The other plants either made fertilizers that did not consume sulfuric acid, or merely mixed them. To an industry that in 1899 produced 3,091,717 tons of product worth $46,011,382, the sale of 71,107 tons of sulfuric acid worth $437,925 is obviously unimportant even though the acid constitute nearly 10 per cent of the total amount offered for sale. Similarly in 1927 when the fertilizer industry sold $190,385,000 worth of goods, its sale of 775,337 tons of sulfuric acid worth $6,158,493 represents again only about 3 per cent of total receipts, though it constitutes one-seventh of the total sales of all sulfuric acid and more than one-third of the amount which the regular sulfuric acid producers were able to market themselves.

The situation since 1929 is indicated in Table 27 and Figure 10. The chart shows the highly seasonal character of sulfuric acid consumption and production, the peak during the winter months and the trough in midsummer. Even seasonally sulfuric acid is not stored so as to regularize pro-

duction and is consumed not only where but when made. Stocks normally average about one-half of one month's production. The quantity of acid purchased from nonfertilizer manufacturers is similarly small, being usually less than one-fourth of requirements. The chart also shows the increasing shipments to consumers who want acid for other purposes than the manufacture of fertilizers.

In Table 27, which gives annual totals of monthly data, the most important fact shown is the transition of the fertilizer industry from a status of deficit to one of surplus. The location of this surplus is shown by a further breakdown of the figures which is given by the census but not reproduced here.

TABLE 27

SULFURIC ACID IN THE FERTILIZER INDUSTRY, 1927–1936

(Thousands of Short Tons, 50° Bé.)*

Year	Production	Purchased or Received		Consumption	Shipped	
		From Fertilizer Manufacturers	From Others		To Fertilizer Manufacturers	To Others
1927........	1,656.9	.....[a]	.....[a]	2,137.1	.....[a]	153.0
1928........	2,226.2	.....[a]	.....[a]	2,473.7	.....[a]	446.1
1929........	2,262.8	.....[a]	470.7	2,445.6	.....[a]	502.6
1930........	2,228.6	.....[a]	451.8	2,476.7	.....[a]	429.1
1931........	1,427.2	.....[a]	263.6	1,351.6	.....[a]	319.8
1932........	952.6	121.6	133.9	770.6	158.3	269.9
1933........	1,367.0	233.1	221.9	1,206.1	219.4	386.9
1934........	1,519.5	246.6	287.1	1,396.0	320.6	333.3
1935........	1,654.7	317.5	220.5	1,343.3	370.0	503.9
1936........	1,746.7	312.2	287.1	1,463.0	296.6	606.9

* Bureau of Census, Department of Commerce, releases on "Sulphuric Acid" of statistics on monthly production, receipts, consumption, shipments, and stocks based on data reported by 64 fertilizer manufacturers for 1936, 69 for 1935, 71 for 1933 and 1934, and 76 from 1927 to 1932.

[a] No data.

It divides the figures given above into two parts, one for the northern area, the other for the southern area, the division line being the south boundary of Virginia projected westward.

A scrutiny of these figures demonstrates a fact already noted —that the fertilizer plants in the South suffered most during the depression. In 1927 when the figures were first collected the two areas produced almost exactly equal amounts and also consumed nearly equal amounts. In 1936 the southern area produced only one-half as much but maintained its proportion of consumption. The difference obviously represents shipments by Northern fertilizer manufacturers of sulfuric acid to consumers other than fertilizer plants, while in the South the deficit status of the fertilizer producers has been maintained.

The location of these fertilizer plants producing sulfuric acid is, of course, primarily in the South. In 1914, for example, out of a total of 194 plants producing sulfuric acid, 128 were fertilizer plants, of which 34 were in Georgia, 18 in New Jersey, 16 in Pennsylvania, 13 in South Carolina, 12 in North Carolina, 11 each in Alabama and Ohio, and 10 in California.

Sulfuric acid is also a secondary product in the explosives industry, where it is frequently mixed with nitric acid to form what is commercially called "mixed" acid. Because of its utility in nitrating organic substances such as glycerin, cellulose, and carbolic acid, its manufacture has grown rapidly with the manufacture of nitrobenzene, of picric acid, of pyroxylin (for varnishes, smokeless powder, plastics, and photography), but especially of nitroglycerin, dynamite, and guncotton. The amount manufactured by the explosives industry has been small and the amount sold, while from one-fourth to one-half of that produced, has amounted to only one per cent of the aggregate tonnage of sulfuric acid sold. Some of the reclaimed acid has come from the explosives industry, the 7,069 tons in 1909 worth $63,000 definitely coming, according to the census, from the plants of 13 explosives manufacturers. Again, in 1919, 44,657 tons, or 9.4

per cent of the total amount of reclaimed acid, came from the explosives industry, the rest coming from the petroleum industry. Most of it, however, is re-used and in so far as it is "spent" is brought back to sufficient strength by adding new acid. In any event the explosives industry cannot be said to be a formidable competitor.

Most important among the industries in which sulfuric acid finds definitive consumption and increasing production as a secondary product is the "chemicals not elsewhere classified" industry. But since even in the census reports this division has been merged with the regular industry, the two will be considered together in chapter ix. It will not be discussed as a competitor for the simple reason that at the present time it is the industry itself. The old-line simple production of sulfuric acid for its own sake has been steadily losing in importance.

RECLAIMED SULFURIC ACID

The most important source (90 per cent in 1919) of the reclaimed acid sold on the market is the petroleum industry. Every gallon of gasoline or kerosene sold to the consumer has been scrubbed with sulfuric acid to remove foul-smelling hydrogen sulfide, corroding sulfur compounds, and gummy, tarry materials which discolor the product as it comes from the stills. The technique is simply one of putting the oil in an agitator, mixing in from one to two per cent of concentrated sulfuric acid, blowing air through it, and finally separating the "sludge acid" containing the impurities. This is then treated by processes that amount to burning off the impurities. As high as 95 per cent of the acid is recovered. Originally none of it could be re-used, but at the present time a good deal of it is.

The table below assembles the fragments of available statistics on the matter. Note that the figures do not make pos-

sible a determination of the amount actually produced by petroleum refineries except for the period from 1904 to 1921, nor the amount sold by them after 1927. The figures, "Sold Reclaimed," for the petroleum industry, moreover, cannot be squared with the amounts reported for sale of all reclaimed acid, the amounts and the average prices realized

TABLE 28

SULFURIC ACID IN THE PETROLEUM INDUSTRY, 1904–1931
(Short Tons)*

Year	Purchased	Made and Consumed	Reclaimed and Reused	Sold Reclaimed (66° Bé. Basis) Tons	Value in Dollars	Number of Establishments[a]
1904.		49,379		165,104	$400,480	
1909.		48,580		133,215	402,295	
1914.	290,455	38,440		89,792	491,380	14
1919.	503,920	18,140		136,320	687,302	65
1921.		109,149		110,544	605,184	34
1923.			340,012	64,454	392,217	64
	Purchased or Produced					
1925.	820,371		345,453	67,410	388,225	66
1927.	872,956		343,787			66
1929.	1,007,590		476,273			69
1931.	900,247		461,585			69

* Bureau of Census reports on "Petroleum" in censuses of manufacture for the respective years.

[a] This represents the number of establishments of all kinds reported by the Bureau of the Census as producing reclaimed acid in its reports on "Chemicals" in the censuses of manufacture.

[b] No data.

being too far apart. In the years since 1923, however, they may very readily be included. A strong presumption that the acid given in Table 28 under "Reclaimed and Reused" is included in the figures given under "Reclaimed" in Table 24 is raised by the fact that in 1919 more than 34 per cent of the total was reclaimed in eight plants in the state of New Jersey. The Standard Oil Company was then operating one of the largest sulfuric acid plants in the United States at

Bayonne. The other plants were, in the order of their importance, in Indiana, New York, and California. Again, in 1931, out of a total of 69 establishments producing reclaimed acid, 13 were situated in Texas, 9 in Pennsylvania, 8 in California, 6 in Illinois, 6 in New Jersey, 4 in Ohio, 3 in Indiana, and 3 in Oklahoma. In both 1919 and 1931 the geographical distribution of the reclaimed-acid plants maps out the oil refineries in the United States.

While the petroleum industry may or may not re-use all the acid it recovers (on balance it is, of course, a large consumer), it probably shares with the reclaimed-acid industry in general a responsibility for upsetting on occasion the local market in which one of its plants producing reclaimed acid operates. In 1921, for example, while the total production of all reclaimed acid was only 200,861 tons, as opposed to 473,555 tons in 1919, the proportion sold jumped from 20 per cent to 84 per cent, or in absolute amounts from 95,000 to 168,000 tons. Similarly in 1931 the percentage of reclaimed acid for sale is unusually high. This may reflect unusual stability of demand for sulfuric acid in the vicinity of the acid-recovery plants; but, if so, it should be noted again in Table 26, not without considerable price concession. In fact, in 1931 reclaimed acid sold at less than half the average price of all acids, whereas in 1923 it sold for almost the identical amount. Probably, therefore, the large percentage sold during years of depression reflects by-product pressure upon the regular producers, pressure which aggravates their competitive problem in the same manner as would dumping in international trade and "freezing out" tactics on the part of monopolies.

SULFURIC ACID FROM ZINC BLENDE ROASTING PLANTS

The manufacture of sulfuric acid as a by-product of smelter operations was pursued abroad as early as the year

1855, when a plant at Stolberg, Germany,[1] began to make it from gases evolved by roasting a zinc sulfide ore called sphalerite. In 1872 the sulfur-bearing burner gases from copper smelters began to be used at Altenau, Germany. But it was not until 1882 that by-product sulfuric acid from zinc ores was produced in the United States. In that year the Matthiesen and Hegeler works began to produce it from sphalerite at La Salle, Illinois. Now these gases are used at numerous acid plants which "may be at zinc smelters and zinc oxide plants, at roasting and magnetic separating plants, at the mines or nearer the acid markets, the roasted concentrates being shipped to the smelters or to the other zinc plants."[2]

At first there was but little increase in its production because a number of special technical problems had to be solved. The roaster gases are not a very suitable raw material; for although their cost is nothing, they are usually very dilute, owing to the small sulfur content of the ores. Moreover, in certain cases, for example, zinc blende, sufficient air must be introduced, not only to burn the sulfur but also to oxidize the zinc. This means extra dilution with nitrogen and carbon dioxide, often to the extent of 50 per cent or more. Consequently more chamber space is required, which increases the interest, maintenance, and depreciation charges per ton. Again, the gases fluctuate somewhat in their composition, so that niter efficiency is low. Even under fairly good circumstances the niter consumption per ton of acid is roughly double the ordinary amount used when pyrites is the raw material. Furthermore, the capacity of the Gay-Lussac tower must be larger per unit of chamber space. The gases

[1] C. E. Munroe, "Chemicals and Allied Products," in Bureau of the Census, *Census of Manufactures, 1905* (Washington, D.C., 1908), X, 408.

[2] United States Department of Commerce, Bureau of Mines, *Mineral Resources of the United States, 1930* (2 vols., Washington, 1933), Vol. I (*Metals*), p. 442.

TABLE 29

By-Product Sulfuric Acid from Zinc Smelters, 1919–1935

(Thousands of Short Tons, and Thousands of Dollars)*

Item	1919	1921	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
Number of establishments	14	14	11	22	22	22	22	21	21	21	21	20	18	14	...
Total tonnage of acid sold (60° Bé. basis)	502	287	384	835	1,044	1,053	974	1,057	1,188	942	726	528	568	483	...
Value of amount sold	6,165	3,404	3,375	8,452	10,095	10,775	10,341	11,187	12,269	9,733	7,162	4,611	4,745	4,139	...
Total acid produced from zinc blende (60° Bé. basis) (cf. Tables 24 and 25)	...[a]	...[a]	...[a]	520	596	564	589	559	627	537	427	341	355	407[b]	443
Acid made from sulfur by zinc industry (60° Bé. basis)	...[a]	...[a]	...[a]	420	537	517	503	546	647	474	381[c]	244	242	89	...
Total produced (60° Bé. basis)	502	287	384	940	1,132	1,082	1,091	1,105	1,274	1,011	808	586	598	496	...
Primary zinc production (short tons)	452	198	508	516	556	612	577	592	612	489	292	207	306	355	...
Blende used, short tons	...[a]	...[a]	...[a]	529	611	530	626	621	683	565	439	341	367	422[d]	...
Acid reported as 50–60° Bé.															
Produced (60° Bé. basis)	397	233	290	507	616	647	605	643	695	549	390	290	346	359[b]	...
Sold (60° Bé. basis)	389	196	290	464	600	615	572	618	658	519	373	275	342	344[b]	...
Value of acid sold: Total	4,698	2,155	2,454	4,204	5,176	5,840	5,588	6,109	6,336	4,996	3,279	2,086	2,576	2,715	...
Average per ton (actual dollars)	$12.06	$11.00	$8.45	$9.05	$8.63	$9.49	$9.76	$9.89	$9.63	$9.63	$8.78	$7.60	$7.54	$7.90	...
Sulfur used, short tons	...[a]	...[a]	...[a]	110	142	137	133	147	176	126	101[c]	65	65	23	...
Acid reported as 66° Bé. and stronger															
Produced (66° Bé. basis)	79	72	77	354	389	402	401	384	482	385	348	246	210	...	...
Consumed at works (66° Bé. basis)	5	7	..	40	47	50	49	35	68	51	46	37	25	...	...
Sold (66° Bé. basis)	74	65	77	314	370	365	334	366	442	353	294	211	189	116	...
Value of acid sold: Total	1,467	1,249	921	4,249	4,918	4,935	4,753	5,077	6,382	4,868	3,884	2,528	2,169	1,424	...
Average per ton (actual dollars)	$19.87	$19.33	$12.00	$13.75	$13.29	$13.53	$14.21	$13.89	$14.45	$13.79	$13.21	$11.95	$11.51	$12.32	...

* For data up to 1923, the Bureau of the Census; from 1924 on, the Bureau of Mines, Department of Commerce, in successive issues of the *Mineral Resources of the United States* and the *Minerals Year Book*.

[a] No data.
[b] Includes acid made from a small quantity of foreign blende.
[c] Includes acid made from a small quantity of pyrites.
[d] Includes small quantity of foreign blende.

also contain extra amounts of various impurities, which make the flue-cleaning, tank-washing, and other expenses larger than in ordinary plants. A period of experimentation had to elapse, therefore, before the industry could really begin to expand.

By 1911, however, zinc smelters were producing about 10 per cent of the total sulfuric acid sold in the United States. During the World War this percentage nearly doubled (see Table 25, above) and the tonnage in 1917 was nearly four times that of 1911. Inasmuch as the tonnage of zinc produced increased only twofold, it is clear that zinc manufacturers were increasing their production of sulfuric acid by adding pyrites or sulfur to their smelting ores or by otherwise enriching the roaster gases. The primary reason for this rebudgeting of their efforts was, of course, the increased demand for 60° Bé. acid in Illinois, Ohio, and Pennsylvania, where the zinc smelters are situated. Note in Table 26 that by-product acid from the zinc industry commanded a top price.

The manner in which zinc blende roasting plants are able to respond to the market demand for sulfuric acid stands out clearly from the detailed statistics of the industry in Table 29. Notice that the number of establishments increased during the prosperous 'twenties from 11 in 1923 to 22 in 1927 and went back down to 14 in 1934. Note, too, that the amount of acid sold by these plants more than doubled in 1924 and reached a figure of nearly 1,200,000 tons in 1929, or more than a fifth by volume and a fourth by value of all the acid sold by all industries. A similar flexibility appears in the total volume of acid produced, the amount increasing almost fourfold between 1921 and 1929 and shrinking by more than 60 per cent between 1929 and 1934. A closer inspection shows that most of this flexibility is due to the portion produced from sulfur, that figure increasing from less than

50,000 tons in 1921 to nearly 650,000 tons in 1929, only to drop back to about 90,000 tons in 1934. No such fluctuation is present in the amount produced from zinc blende.

A glance at the second group of items shows that this portion varies closely with the amount of primary zinc produced and of course with the amount of raw material or zinc blende used. That it should also show close correspondence with the amount of acid of 50° to 60° Bé. strength produced may at first seem curious, but 60° Bé. acid is the strength of acid that flows directly from the Glover towers. It is the first marketable form of the semi-inescapable by-product from zinc blende roasting operations. Only a very small percentage of it is consumed at the plant. In years of depression such as 1921 and 1934 its sales represent by volume from two-thirds to four-fifths of the total zinc by-product acid sold. In years of prosperity such as 1929 it becomes only about one-half of the total.

The third group of items, on the other hand, shows unusual flexibility, the amount of 66° Bé. acid varying from less than 25,000 tons in 1921 to more than 480,000 tons in 1929, but shrinking to 114,000 tons in 1934. The extraordinary jump in 1924, while not explained by the Bureau of Mines in its reports, must to some degree represent a break in the statistical series. On the other hand, the 50 per cent shrinkage in volume of 66° Bé. acid production between 1933 and 1934 is also an unusual jump, which, while showing in part the influence of competition from contact acid production, indicates in the main how quickly zinc roasting plants can adjust their production to the conditions of competition. In short, the 66° Bé. acid is an optional by-product, that is, a common or allied product.[3]

[3] For the implications of this distinction in economic theory, see my article, "Joint Costs in the Chemical Industry," *Quarterly Journal of Economics*, (May 1930), XLIV, 450–55.

SULFURIC ACID FROM COPPER SMELTERS

The acid produced by copper smelters was originally an unwanted but compulsory by-product. This appears clearly from the record of its price in Table 26, above; for though the computations for the copper plants are made on the basis of the same strength of acid as for the zinc plants, the average price realized is not only consistently lower but in some years less than one-half that obtained by the zinc producers. Moreover, during the war the output instead of doubling increased merely 20 per cent (1917 over 1914). Similarly in 1921 it contracted but 34 per cent from the 1917 figure. Here clearly the amount of sulfuric acid produced depends directly upon the quantity of copper ore reduced and but little on the forces of demand and supply for sulfuric acid. Its price is at all times remarkably low, a fact explicable not solely on the grounds of expenses of production but partly on the basis of the marginal vendibility, in the market area adjacent to the copper smelters, of the amount of sulfuric acid which the economic conditions affecting copper production dictate.

The difficulties of utilizing the sulfur content of copper ores are in the main the same as those already noted in the case of zinc blende, with the additional handicap that some of the copper producers are forced to use blast furnace gases from ores running, for example, in the case of the Tennessee concerns, about 2½ per cent copper, 30 per cent iron, 20 per cent sulfur, 30 per cent insoluble matter, 10 per cent lime, 3 per cent zinc, and 3 per cent aluminum oxide. The high carbon dioxide and unusually low oxygen content of the resultant gases makes the reactions in the chambers very sluggish and the niter loss unusually heavy. Moreover, the sulfur content of the gas is bound to vary,[4] since the blast

[4] Philip de Wolf and E. L. Larison, *American Sulphuric Acid Practice* (McGraw-Hill, New York, 1921), pp. 65, 66.

furnace must be charged several times a day, and cleaned at least once daily. The production of acid under such conditions represented at first a blind sally into an uncharted area of commercial enterprise. Copper smelters, therefore, generally were slow to begin the manufacture of sulfuric acid, particularly since the raw material floated itself off into space.

But that was precisely the trouble. Sulfur dioxide in common with certain other gases[5] in chemical manufacture, when present in sufficient quantities, causes considerable damage to vegetation. Thus even as early as 1892, one writer described the damage done by the waste gases from certain blast furnaces in Tennessee in the following terms:

> Entering this valley by means of a winding trail over the towering mountains to the eastward, there is presented a picture of mournful strength and lifelessness, strangely impressive in every sense—a desolate valley with irregularly placed knobs of vari-colored rock, mineralized and artificial openings, denuded of all vegetation by the scouring action of sulphurous gases which swept over it for many years.[6]

Protection against nuisances, however, is recognized by our legal system as an individual right. Any act, any omission of precautions, any use of property which results in polluting the atmosphere with obnoxious or offensive gases and vapors, thereby causing material physical discomfort and annoyance to persons residing in the vicinity or injury

[5] "The usual gases which give rise to complaint in manufacturing localities are: chlorine, which is emitted from pottery kilns and ceramic products manufactories, and plants for the electrolysis of halides; hydrochloric acid which is produced by the combustion of coal (i.e., sea coal), by pottery kilns, and ceramics, nickel and cobalt smelting, glass, fertilizer, chloride of lime and soda manufactories; sulphur dioxide and sulphuric acid from coal, coke and gas, copper smelting; fluorine and hydrofluoric acid which are emitted from phosphate fertilizer and heavy chemical plants." Charles Baskerville, "The Smoke Problem and the Community," *Journal of Industrial and Engineering Chemistry* (August 1910), p. 358.

[6] W. H. Adams, "Pyrites as a Material for the Manufacture of Sulphuric Acid," *Journal of Analytical and Applied Chemistry* (1892), Vol. VI, No. 1, p. 22.

to their health and property, is a nuisance, for which suit can be entered for damages.

Many firms were at first content to pay such damages, regarding them as a regular expense of production. But as markets developed they began to process the waste product voluntarily. Where, however, the profit motive was lacking or insufficient, legislation frequently resulted. In the English Leblanc soda industry, for example, the passage of Lord Derby's Alkali Act was found necessary. But in the United States such regulatory legislation is a matter of individual state action.

The situation in Tennessee was a peculiar one. The smelters are located near the boundary line between Tennessee and Georgia. Considerable damage had been done to the property of persons in Georgia for years, yet so long as the legislature in Tennessee refused to act, there seemed to be no remedy. Finally the state of Georgia brought suit against the Tennessee Copper Company, and the Ducktown Sulphur, Copper, and Iron Company in the federal courts. In 1906 there followed a decision of considerable importance. The United States Supreme Court held that a state not only had the right to protect its forests but could also demand protection for its citizens when their property is damaged by operations in another state. As a result a permanent injunction was issued against permitting the gases to escape.

The problem facing the two concerns presented unprecedented difficulties. The Tennessee Copper Company, with its seven large blast furnaces, handled 400,000 tons of sulfide ore annually, and the Ducktown Sulphur, Copper, and Iron Company about 150,000 tons. The former had to devise and construct the largest acid plant ever built,[7] one which in

[7] F. B. Laney, "The Manufacture of Sulphuric Acid from Smelter Fumes at Ducktown, Tennessee," United States Geological Survey, *Mineral Resources of the United States, Calendar Year 1911* (2 parts, Washington, D.C., 1912),

1908 had a rated capacity of 120,000 short tons of 60° Bé. acid annually and by 1910 had been enlarged to 180,000 tons. The latter, as its name indicates, had been organized as early as 1891 to utilize the sulfur, and in 1911 was operating a plant with an estimated capacity of 50,000 tons yearly.

Fortunately, the manufacture of sulfuric acid proved fairly profitable. The plants were situated near the center of acid-phosphate fertilizer consumption in the United States. Thus in 1909 they were able to contract to sell their entire output for ten years to the International Agricultural Corporation. But the enormous rise in war prices caused this highly profitable contract to bring a deficit. Upon expiration of the contract in 1920, therefore, the Tennessee Copper Company branched out into the fertilizer field for itself, forming the Southern Agricultural Corporation and erecting a 100,000-ton fertilizer plant at Atlanta, Georgia. Today it markets copper, copper sulfate, iron sinter, slag, niter cake, sulfuric acid, and fertilizers, having several fertilizer plants of its own. It is still the largest producer of sulfuric acid in the world, its annual output of 60° Bé. acid ranging from 200,000 to more than 350,000 tons, most of it, though not all,[8] being by-product.

The Ducktown Company, on the other hand, erected a concentration mill in 1920 which by the process of selective flotation concentrated the metal content of its low-grade ores

Part II, p. 961. Some of the dimensions are gigantic, e.g.: Glover towers 50 feet high and 30 feet in diameter; cooling chambers, 88 of them, 70 feet high and some with a base 50 feet square; Gay-Lussac towers, 10 of them, 50, 70, and 75 feet high; and a dust chamber 26 × 36 × 163 feet.

[8] That a minor degree of exibility exists is evident from the following statement concerning its operations in 1927: "At the smelter 12,505 to 31,580 tons of ore per month was handled, according to the demand for sulphuric acid," United States Department of Commerce, Bureau of Mines, *Mineral Resources of the United States 1927* (2 parts, Washington, D.C., 1930), Part I (*Metals*), p. 717.

(40 per cent iron and 30 per cent sulfur) into separate pyrrhotite (copper) and pyrites (iron) concentrates. These, together with a magnetic concentrate secured by a Dings magnetic separator, are roasted at the smelter, and the sulfur dioxide gas evolved is mixed with the gases from the copper blast furnace and converter and conducted to the chamber acid plants. In 1925 it was reorganized under the title of the Ducktown Chemical and Iron Company. In 1929 a contact plant was built to meet the demand for high-grade acid in the petroleum, explosives, rayon, and steel industries. To-day it has achieved complete "integration of its operating units: mines; concentrating mill; roasting, sintering, and acid plants, both chamber and contact; copper smelter; company railroad; tank cars; and storage facilities. This integration covered the transition from the old days of dependence on high grade copper ores alone to the present utilization of all resources and the diversification of products."[9] Its main product utilizing pyrites concentrates as a raw material is at present sulfuric acid, and its production is consequently no longer listed under by-product acid (see Table 24, above). This is likewise true of the Tennessee Copper Company and the Anaconda Copper Mining Company which are now likewise listed as large producers of pyrites rather than of by-product acid.

The fluctuations in by-product acid production appear clearly in Figure 11. The bursts of production during periods of prosperity are particularly evident.

On the other hand, the slump since 1929 is somewhat exaggerated on the chart because some of the largest copper smelters, by utilizing new flotation processes, produce copper and pyrites concentrates high in sulfur content and have become competitors with pyrites mines, a transition of status

[9] "Chemical Industry's Contribution to the Nation, 1635–1935," *Chemical Industries* (Supplement, May 1935), p. 83.

equivalent to that which would occur if a cotton mill by evolution of its own processes would ultimately become a producer of raw cotton. The Ducktown Company instead of a by-product acid producer has become a bona fide or regular sulfuric acid producer, with control over its own raw

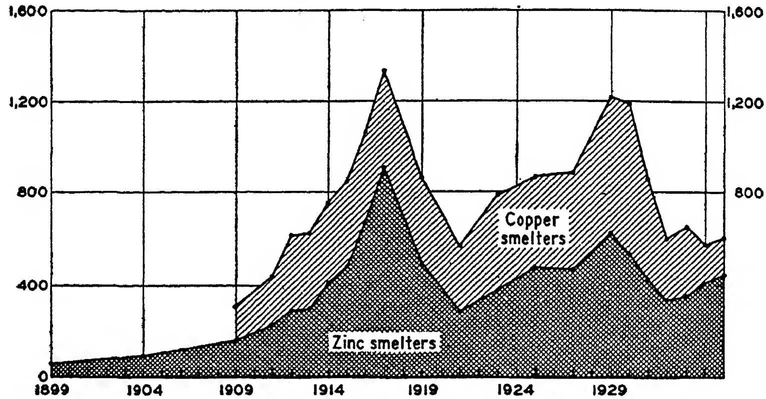


Fig. 11.—By-product sulfuric acid in the zinc and copper industries, 1899–1934 (thousands of tons, 50° Bé. basis). For source of data, see Table 24.

material supply. The Tennessee and Anaconda Copper Companies, among others, have advanced from a status of being compelled to put out by-product sulfuric acid to one of free agents merchandising sulfur in the form either of the acid or of the concentrates and in such proportions as they feel will best meet the exigencies of competition.

CONCLUSION

Interindustry competition in production, sales, or price, so far as sulfuric acid is concerned, follows no general laws of market behavior, nor are there present long-run forces of demand or supply sufficiently strong to tend to establish any one equilibrium level of output or prices. Even the individual producer in the industries in which sulfuric acid is a by-

product or joint product is unable to know what his costs of production are except on the basis of accounting assumptions that are arbitrary and that will certainly yield different results when the main product is copper and when it is zinc. At times and for those plants which the law compels to take care of their waste gases the price at which they are willing to sell sulfuric acid may be even less than the out-of-pocket expense of processing it; that is, they are willing to pay customers to take it, the amount of pay being limited by the cost of the cheapest alternative mode of waste disposal. For plants in which sulfuric acid is a subsidiary product the price of the acid will, of course, have to cover out-of-pocket expenses at least in so far as they exceed the minimum cost of corrosion, watchmen, and so on involved in shutting the plant down entirely. Of course, a price that yields something toward overhead may endure not only for short periods but also for long periods of time if fertilizer or petroleum receipts are made to carry most of the burden. Reclaimed acid similarly comes on the market invulnerable to ordinary market pressures. Price competition for the person who wishes to make his living from the production and sale of sulfuric acid knows little in the way of boundaries so far as costs of production are concerned. Market co-ordination of demand, supply, and price is at best weak. But for other controls interindustry competition would lead to chaos.

VIII. Interarea Competition

Sulfuric acid has from three to four times the bulk of the sulfur and niter necessary to produce it. Moreover, it is a relatively cheap and highly corrosive liquid that in large amounts requires special handling in tank cars or tank wagons and in small quantities necessitates expensive packaging in drums or glass carboys. A two-hundred-mile haul for regular contract delivery of acid over a long period of time is exceptional. Its relatively valuable raw materials, on the other hand, can be shipped almost as readily as coal. Thus plants are usually built close to the point of consumption. The geographic distribution of the industry depends primarily on the location of the demand. Between areas sufficiently large but little vigorous interarea competition exists.

International competition is negligible. Imports, except for the one year, 1926, when they were 28,000 tons, have averaged less than 5,000 tons and run now about 1,000 tons, i.e., about one-sixth of one per cent of domestic production. More than 97 per cent of the imports come from Canada—either from Ontario, where it is made from smelter stack gases and sold to consumers in upper New York State and northern Pennsylvania, or from Trail in British Columbia where it is a by-product in zinc blende roasting operations. In dollar value, again except for the year 1926, imports have ranged from six thousand to one hundred and seventy-six thousand dollars, or from one-half to one-tenth of one per cent of total domestic sales.

Exports of the acid have similarly been insignificant, ranging normally from two to seven thousand tons, worth from fifty to two hundred thousand dollars. Even during the World War, with England, France, and Canada in dire need of it for the manufacture of military explosives, the amount

exported was only 42,000 tons, a good deal less than one per cent of domestic production. The little that was exported during the 'twenties went mostly to Cuba, Mexico, Peru, and Canada in the order named, with Cuba taking about a third, Mexico a fifth, and Peru a fifth of the total exports. Practically all of the exported acid is oleum. Table 30 gives a factual summary.

TABLE 30

IMPORTS AND EXPORTS OF SULFURIC ACID, 1910–1934

(Thousands of Tons and Thousands of Dollars) *

Year	Exports		Unit Value	Imports		Unit Value
	Tons	Value		Tons	Value	
1910........	2.5	61.9	$24.70	0.018	1.1	$59.00
1912........	3.5	71.9	20.50	0.024	0.64	26.20
1914........	6.1	125.9	20.60	3.4[a]	40.6	11.90
1916........	42.0	1,990.5	47.40	3.1	61.4	19.80
1918........	33.9	1,119.9	33.00	5.7	176.2	30.90
1920........	14.5	733.2	50.60	5.4	88.0	16.30
1922........	6.2	201.3	32.40	1.5	29.2	19.50
1924........	5.1	180.0	35.30	7.7	132.5	17.20
1926........	4.6	174.4	37.90	28.0	337.6	12.10
1928........	3.5	148.7	42.50	13.2	160.9	12.20
1930........	2.7	113.9	42.20	0.46	6.2	13.50
1932........	1.5	48.7	32.50	0.75	11.2	14.90
1934........	...	....	.....	0.92	12.7	13.80

* Department of Commerce reports on *Foreign Commerce and Navigation of the United States* for the respective years.

[a] Duty of ¼ cent per pound removed.

SHIFTS IN LOCATION OF ESTABLISHMENTS, 1899–1933

Difficulty and cost of transport of the acid being so large, shifts in geographic distribution of the industry are determined primarily by the relative growth of various demands for it. For it must be made at or fairly near where it is consumed. Even in the case of copper and zinc smelters, the situs of sulfuric acid production is not necessarily determined by the location of the smelters, as it formerly was, but can

be carried to any spot where it may be economical to ship the copper, lead, zinc, or pyrites concentrates. The determining character of shifts in demand is modified but not nullified.

There are several indicia of shifts in geographical concentration. One is the fluctuation in the number of establishments in the various states. Another is the change in the relative percentages of total production comprised by the output of the individual states. A third index of interarea competition is the change in the proportion of total sales which are made by the several states. A fourth appears in the different prices in the various areas, another in the differing average size of establishments, and so forth. Suffice it to say that no one indicator of interarea competition tells the whole story.

In Table 31, below, is shown the fluctuation in number of establishments producing sulfuric acid in the most important groups of states. In the group at the top of the table are shown the establishments producing acid in the vicinity of and for the cities of Boston, New York, and Philadelphia. Most important here has been the decline in the number of plants in the state of New York, largely a result of the widening out of the metropolitan area of New York City, forcing sulfuric acid plants to move into New Jersey,[1] where the advantages of New York Harbor can be combined with those of cheap land, remoteness from residential districts, and inexpensive disposal of waste.

In the second group of states are mirrored the fortunes of the phosphate-fertilizer industry. Note its early concentration in Maryland, South Carolina, and Georgia, its heyday of prosperity before the World War—the number of establishments in all of the states reaching a maximum in 1914—and

[1] Mabel Newcomer, *The Chemical Industry in New York and Its Environs*, Monograph No. 1 of R. M. Haig's *Economic and Industrial Survey* (published by the Committee on a Regional Plan for New York and Its Environs, 130 East Twenty-second Street, New York, 1924), p. 22.

the spread of the industry to Alabama, Mississippi, and North Carolina. Notice also the precipitate drop in 1933, the aggregate number of establishments in this group of states dropping from 67 to 31, or more than half. This is equally true

TABLE 31

NUMBER OF ESTABLISHMENTS, BY STATES, 1899–1933*

Area		1904	1914	1925	1929	
Massachusetts	4	4	3	4	4	3
New York	11	10	6	6	2	3
New Jersey ...	18	13	18	15	14	10
Pennsylvania .	11	16	16	16	16	11
Alabama	3	7	11	9	8	3
Florida	1	1	4	3	4	1
Georgia	15	20	34	19	18	6
Maryland	12	9	7	6	6	5
Mississippi	1	1	5	5	2	..
North Carolina.	6	7	12	11	9	5
South Carolina.	12	11	13	12	11	8
Virginia	5	7	9	8	9	3
Tennessee						
Illinois ...		3	9	11	12	7
Indiana ...		3	2	2	2	2
Michigan .		3	3	3	3	3
Ohio		9	11	10	12	11
Wisconsin		1	1	3	2	2
Louisiana .		3	3	3	5	2
Texas		1	3	6	4	3
California	7		10	6	7	7
United States .	127	149	194	177	171	112

* Bureau of the Census in its reports on "Chemicals and Allied Products" in the censuses of manufactures for the respective years.

in Tennessee, where only one out of the five establishments that produced sulfuric acid in Nashville in 1929 was producing it in 1933.

In the fourth group of states, those containing such large cities as Detroit, Chicago, Cincinnati, and Cleveland, the

most noticeable feature is the rapid growth of the number of establishments in Ohio between 1899 and 1904 and the equally rapid development in Illinois shortly before the World War. A similar growth took place in Texas after the World War when the oil fields there were opened up.

CHANGES IN AREAS OF PRINCIPAL PRODUCTION

The shift of sulfuric acid production away from Pennsylvania and New York to Illinois, Tennessee, and California is shown more strikingly in Table 32. In 1879 about two-

TABLE 32

PERCENTAGE OF TOTAL PRODUCTION, BY STATES, 1879–1929*

State	1879	1889	1899	(1904–1914)	1919	1925	1929
Massachusetts .	9	5	7		2.0	3.0	3.5[b]
New Jersey	19	14	16		11.6	10.8	13.7
New York	12	8	7		2.2	1.9	2.3[b]
Pennsylvania ..	26	15	14		10.1	10.7	11.6
Georgia			5		4.9	3.8	2.9
Maryland		13	10		8.8	9.4	8.9
South Carolina		16	11		3.0	2.7	1.3
Tennessee					7.0[d]	8.7	8.9
Illinois	1				9.8	8.2	9.4
Ohio ...	10				6.7	7.3	7.3
California					7.5	6.1	4.7[e]

* Computed from figures of production of sulfuric acid by states in Bureau of Census reports on "Chemicals and Allied Products" in the censuses of manufactures for the respective years.

[a] Data only for sales and amounts purchased by states; no production figures.

[b] Estimated; census giving figures only for combined production of Connecticut, Massachusetts, Delaware, and New York.

[c] No data, but probably less than one per cent.

[d] Estimated; production of Tennessee Copper Company alone being 266,627 tons of 60° Bé. acid in 1919.

[e] Estimated; census giving figures only for combined production of California, Arizona, Montana, Utah, and Washington.

thirds of the total output was produced in the North Atlantic States, and more than a fourth in or near Philadelphia. West

of the Alleghenies only Ohio produced appreciable quantities of it, in and around Cincinnati. In the next ten years there occurred an outburst of activity in the South as the phosphate deposits of South Carolina and later of Florida were made available.

Contrast the situation after the World War. Massachusetts and New York produce less than one-third as large a percentage of the total output as they did in 1899. Pennsylvania and New Jersey produce each about one-ninth of the total supply of sulfuric acid. Production in the fertilizer producing states declines to small percentages, that of South Carolina going down from 16 in 1889 to 1.3 in 1929. Notice that Tennessee more than quadruples its percentage of the greatly increased total, the figure going up from less than 2 per cent in 1899 to nearly 9 per cent in 1929, a fact reflecting the development of by-product acid from copper smelters. Illinois increases its percentage fivefold between 1899 and 1919, a result in part of the increase in manufacturing activity around Chicago and in part of the outpouring of by-product acid from zinc smelters. The almost apocryphal new wealth discovered in the Texas and California oil fields caused similar bursts of production of sulfuric acid in those states after the World War. As a result the four North Atlantic States which produced two-thirds of all sulfuric acid in 1879 produced but little more than one-fourth of the total in 1919. The production of sulfuric acid became widely diffused.

SHIFTS IN THE PATTERN OF PRICES AND SALES

Probably no one factor shows more clearly how limited is the amount of interarea competition than a sample of the average prices realized per ton of acid sold. The differences in prices between the various areas as shown in Table 33 are not only considerable but abiding. In 1879, even in the

TABLE 33

Prices and Sales of Sulfuric Acid, by States, 1879, 1889, 1914, 1929*

Area	1879	1889			1914			1929			Percentage of Total Sales by Value		
	Average Price	Thousand Tons	Thousand Dollars	Average Price	Thousand Tons	Thousand Dollars	Average Price	Thousand Tons	Thousand Dollars	Average Price	1889	1914	1929
Massachusetts	$29.00	5.5	82.9	$15.10	53.4	641.3	$12.00	74.4[a]	862.7[a]	$11.60	1.6	4.2	1.9[a]
New Jersey	18.50	95.2	1,305.2	13.70	399.7	3,085.2	7.70	622.8	4,778.9	7.70	25.1	20.0	10.5
New York	21.20	52.9	878.3	16.60	64.0	532.9	8.30	93.0[a]	977.5[a]	10.50	16.9	3.5	2.1[a]
Pennsylvania	28.20	105.8	1,008.8	9.50	362.3	2,498.1	6.90	795.8	6,804.1	8.50	19.4	16.2	14.9
Georgia	.....[b]	25.5	126.2	4.90	20.1	115.2	5.80	74.3	537.5	7.20	2.4	.7	1.2
Maryland	15.50	54.9	372.4	6.80	187.9	1,194.8	6.40	322.4	2,591.3	8.00	7.2	7.8	5.7
South Carolina	27.70	3.7	21.8	5.90	30.7	176.5	5.70	41.4	318.4	7.70	.4	1.1	.7
Virginia	22.50	4.0	32.0	8.00	73.4	411.2	5.60	107.6	928.5	8.60	.6	2.7	2.0
Tennessee	.....[b]	3.5	35.0	10.00	264.5	1,061.4	4.00	610.6	2,910.0	4.80	.7	6.9	6.4
Illinois	29.50	15.3	170.4	11.10	349.2	1,848.0	5.30	727.0	5,892.0	8.10	3.3	12.0	12.9
Ohio	31.80	32.3	483.4	15.00	142.8	983.6	6.90	512.3	3,913.9	7.60	9.3	6.4	8.6
Texas	.....[b]	....[b]	.....[b]	.....	.....[b]	.....[b]	....	225.6	1,785.6	7.90	...[b]	...[b]	...
California	49.70	10.6	244.5	23.10	114.1	945.2	8.30	415.1[a]	4,307.9[a]	10.40	4.7	6.1	9.5[a]
Total for United States	23.80	448.4	5,199.0	11.60	2,338.3	15,395.1	6.60	5,816.2	45,575.2	7.80	...	...	...

* Computed from Bureau of Census reports on "Chemicals and Allied Products" in the censuses of manufacture for the respective years.

[a] Figures for 1925, no data being available for these states separately in 1929.

[b] No data.

compact New York–New Jersey area the average price of the acid in New Jersey is \$18.50 and in Pennsylvania \$28.20, and the maximum price, \$49.70, in California, is more than three times the lowest price, \$15.50, in Maryland. Such differences may be due to differences in strengths of sulfuric acid marketed, in the quantity lots in which it is sold, in the types of consumer, in requirements of purity and quality, in types of contract, whether long-term or spot transactions, in marketing and shipping and transport expenses not only of the finished product but of the raw materials, in wage levels, and the like. In any event, they show that manufacturers of sulfuric acid in one area need pay little attention to direct competition from manufacturers in other areas not more than two or three hundred miles away.

Notice that in 1889, although the structure of the differences has changed in some respects, the range of differences, while less in the absolute sense, is relatively no smaller. Sulfuric acid is still the most expensive in California, averaging no less than four times the price of acid sold in Georgia (\$21.20 versus \$4.90). But the roles of Pennsylvania and New Jersey are now reversed, the average price realized in the former state being \$9.50 and \$13.70 in the latter. That is, while the prices of sulfuric acid on the average dropped somewhat more than half between 1879 and 1889, that in Pennsylvania went down by two-thirds, while in New Jersey it dropped only one-third. Massachusetts and New York show a similar reversal of roles.

In 1914 the range of differences narrows considerably both absolutely and relatively, Massachusetts now realizing the highest average price per ton of acid sold—\$12.00 as opposed to \$4.00 in Tennessee. The change in the structure of the differences has been even more striking. In the New York–New Jersey area the greatest reduction in price, exactly 50 per cent, has taken place in New York, while that in

Boston is only 10 per cent and that in Philadelphia 30 per cent. On the other hand, in the Southern States the average price realized per ton has varied but little, that in Georgia being even higher in 1914 than in 1889 and in the others, with the single exception of Virginia, the amount of the reduction being less than 10 per cent.

Notice, however, the new situation in Tennessee, Illinois, Ohio, and California. In the first three states the price of sulfuric acid in 1914 is less than half of what it was in 1889. No doubt the pressure of by-product acid from copper and zinc smelters for a share in the market is in large part responsible. But that does not account for the even larger (60 per cent) decline for the period in the average realized price per ton of sulfuric acid in California, nor does any other force save that of competition among producers in California itself.

By 1929 the pattern of sulfuric acid prices became more stable. While the average price in Massachusetts, $11.60, is more than twice that in Tennessee, $4.70, the experience of the various areas presents no such contrasts as formerly. The rise in prices from a general average of $6.60 in 1914 to $7.80 in 1929 is participated in by every state except New Jersey. The area of lowest prices continues to be Tennessee and the cordon of states around it—Georgia, South Carolina, Kentucky, Ohio, Illinois, Missouri, Arkansas, and Mississippi—the reasons primarily being the outpouring of by-product acid, and the demand in fertilizer manufacture for acid of weaker strengths.

The censuses of manufactures in recent years unfortunately do not give the figures by states for the value of the amount of sulfuric acid sold in the various concentrations, but certain rough comparisons can be made from the data available for 1899 and 1919 which have been put together in Table 34. The areas in which the general average of all

strengths when reduced to a 50° Bé. basis was low continue to appear at the lower end of the scale here. The same grade of acid sells at varying prices even in contiguous states such as New York and New Jersey. The price of all strengths in Maryland is consistently lower than it is in Pennsylvania. In short, the diversity in pattern of prices persists.

TABLE 34

PRICES ACCORDING TO STRENGTHS, BY STATES, 1899 AND 1919*

State	1899			1919			
	50° Bé.	60° Bé.	66° Bé.	50° Bé.	60° Bé.	66° Bé.	Oleum
Massachusetts	$ 9.40	.....[a]	$15.00	.....[a]	.....[a]	.....[a]	.....[a]
New York	10.50	$18.00	19.50	$13.90	$19.30	$27.30	$21.20(?)
New Jersey	6.60	.....[a]	13.50	12.50	16.70	19.10	23.00
Pennsylvania	7.70	14.30	17.40	11.80	14.30	18.80	22.20
Maryland	5.70	.....[a]	15.00	11.50	11.70	16.50	.....[a]
Ohio	.....[a]	.....[a]	13.10	9.70	11.90	16.80	.....[a]
Alabama	8.50	.....[a]	.....[a]	.....[a]	16.50	19.70	.....[a]
Georgia	6.30	.....[a]	.....[a]	15.60(?)	9.80(?)	32.40(?)	.....[a]
Illinois	.....[a]	.....[a]	18.00	10.20	10.00(?)	22.70	27.20
Louisiana	.....[a]	40.00(?)	42.00(?)	9.10	14.50	19.00	.....[a]
California	12.50	14.10	19.10	11.10	9.20(?)	16.60	46.70

* Computed from data on tons and value of sales of various strengths as given by the Bureau of the Census in its reports on "Chemicals and Allied Products," in the volumes on manufactures in censuses for 1900 and 1920. Question marks indicate original data of considerable dubiety.

[a] No recorded sales.

Going back to Table 33, let us give brief attention to the last column on the right, which shows changes in the percentages of total sales enjoyed by the principal acid-producing states. The topmost group of states, and especially New York, have steadily lost ground, their aggregate slice of the market declining from two-thirds to slightly more than one-fourth, while that of California, Tennessee, and Illinois has doubled and quadrupled. Comparing the figures of sales given here with those given for production in the preceding table, notice

how utterly divergent the sales figures are from the production figures for Georgia, Maryland, and especially South Carolina, which, while producing 16 per cent of the total in that year, marketed only four-tenths of one per cent. On the other hand, the share of the market enjoyed by New Jersey, New York, and California in that year is almost double their respective shares of total production. Similar differences between the various states persist throughout the period, indicating, of course, the varying extent to which the acid is consumed where made and marketed in the form of derivative products such as superphosphates.

VARIATION IN SIZE AND TYPE OF PLANT BY STATES

A rough idea of the intricacy and variation in detail of the pattern of production (returning to the use of data by states) is given in Table 35. In the first place, note the difference between the states in the percentage consumed where made. Plants in California, Illinois, Ohio, Pennsylvania, and Tennessee, on the whole, produce to sell. The plants in Massachusetts and in Area C produce from two-thirds to four-fifths of their sulfuric acid for their own use. Notice next the considerable variation in the average output per establishment, ranging from 126,000 tons of 50° Bé. acid annually in Maryland to less than 10,000 tons in Mississippi. Even when the figures are reduced to a per-plant basis the range varies from 58,000 tons in Maryland to about 7,000 tons in Mississippi.

These, of course, are averages, and in the case of Tennessee the figure is definitely misleading. There are not seven establishments there of equal size, but five small plants, one moderately large, and one very large. "The outstanding plant is that of the Tennessee Copper Company at Copperhill, Tennessee, which is credited with a possible daily production of 1,100 tons of 60° Bé. acid in twenty-four

hours. This company also concentrates about 100 tons per day of acid from 60° to 66° Bé."[2] Near by at Isabella is the plant of the Ducktown Chemical and Iron Company with a daily capacity of 200 tons of 60° Bé. acid. Probably three-fifths to two-thirds or more of Tennessee's output of sulfuric acid was produced by these two concerns in 1929. The plants in and around Nashville are no larger than the ordinary plants in the South.

In a much less striking sense the same variations in capacity and output among plants exist in the other states. Moreover, the smallness of the number of plants in the individual states brings about a considerable looseness of precision in the average. The figure of average production of plant also varies cyclically, definitely going up in periods of prosperity, that is, full utilization of capacity, and going down in periods of depression despite the at times wholesale elimination or cessation of production on the part of small plants. Furthermore, the figure put on a per-establishment basis varies arbitrarily between states because of the variable number of plants owned by one establishment.

Average production per plant, while not indicating the size of the managerial and sales unit as between states, does show the differences in size of the technical unit, but again only for states using the same processes. Notice that of the states in which the average production per plant considerably exceeds the general average all, with the single exception of Maryland, produce a good deal of 100 per cent sulfuric acid or higher strengths, indicating a relatively large proportion of contact acid plants. Note, too, that of the states in which the average production per plant is relatively low all, with the exception of Louisiana and Wisconsin, produce exclusively or predominantly 50° Bé. acid, indicating a

[2] W. H. Scott, "The Chemical Industry in Tennessee," in *Chemical and Metallurgical Engineering* (January 1927), Vol. XXXIV, No. 1, p. 22.

TABLE 35

PRODUCTION ACCORDING TO STRENGTHS, BY STATES, IN 1929

(Thousands of Tons) *

Area	Total Production (50° Bé. Basis)	Percentage Consumed Where Made	Average Production per Establishment (50° Bé. Basis)	Average Production per Plant	50° Bé.	60° Bé.	66° Bé.	100%	Other Strengths
Area A			*(Actual figures)*	*(Actual figures)*					
Massachusetts[a]	214[a]	65[a]	53,500[a]	26,800[a]	153	...	76	331	1
New Jersey ...	1,165	47	83,000	51,000	117	12	33	597	13
Pennsylvania .	984	19	61,500	39,000	51	398	34	233	5
Maryland	757	57	126,000	58,000	504	127	21	...	39
Area B									
Ohio	621	18	52,000	33,000	62	34	..	320	..
Michigan, etc.[b]	310[b]	22[b]	44,000[b]	26,000[b]	15	17	27	143	1
Area C									
Alabama	138	46	17,000	9,200	54	44	..	18	..
Georgia	253	71	14,000	7,900	212	33	..	..	..
Mississippi[a] ...	46[a]	81[a]	9,200[a]	6,600[a]	46[a]	..	..	..	..
North Carolina	140	80	15,500	8,200	128	10	..	..	..
South Carolina	123	66	11,000	9,500	117	5	..	..	..
Virginia	214	50	24,000	24,000	107	..	..	66	..

Area D									
Tennessee	757	19	108,000	84,000	74	504	35	..	..
Area E									
Illinois	802	9	67,000	47,000	56	231	..	255	24
Wisconsin[a]	48[a]	25[a]	16,000[a]	12,000[a]	..	13	..	18	..
Area F									
Louisiana	141	31	28,000	15,700	52	..	..	39	16
Texas	328	31	82,000	41,000	26	..	58	52	83
Area G									
California[a]	430[a]	4[a]	71,000[a]	36,000[a]	..	..	35	234	..
The United States	8,491	31	49,000	29,300	1,879	1,527	354	2,407	182
For sale					410	1,397	258	1,852	178

* Adapted and computed from data given in the census of manufactures for 1929 in its report on "Chemicals and Allied Products.'

[a] Data for 1925 because the census of manufactures for 1929 groups the state with other states.

[b] Data apply to the states of Michigan, Indiana, and Wisconsin.

large proportion of chamber plants. In the former group, in order of decreasing size of plant from extra large to average, are New Jersey, Illinois, Texas, California, and Ohio, respectively. In the latter group, in order of increasing size of plant from extra small to average, are Mississippi, Georgia, North Carolina, Alabama, South Carolina, and Virginia. Excluding the special case of Tennessee, the largest average size of plant, that in Maryland, is nine times the smallest average, that in Mississippi. Such enormous variations cannot be haphazard deviations from an optimum size of plant. They show the nonhomogeneous character of the markets.

AREAS OF COMPETITION IN 1929

Thus far the problem of interarea competition has been treated as if sulfuric acid markets were delimited by state boundary lines, for the simple reason, of course, that such is the regional breakdown of the data as given by the census. Actually, with but few exceptions, the important market foci are manufacturing and metropolitan areas, especially those in which is concentrated the production of fertilizers, petroleum products, coal products, steel, and textiles, including rayon. It is in the competition in these items that the efficiency of sulfuric acid manufacture plays an important role. It is the success of the various areas in the sale of these items that determines the amount and kind of sulfuric acid produced and marketed.

In 1929 the number of plants grouped around the various large cities was as follows: New York, 22; Philadelphia, 12; Chicago, 11; Baltimore, 11; Boston, 9; Pittsburgh, 8; St. Louis, 8; Charleston, S.C., 8; San Francisco, 7; Savannah, Ga., 7; Wilmington, N.C., 6; Cincinnati, 6; Birmingham, Ala., 6; and Los Angeles, 5. This, of course, gives a highly imperfect picture of the relative importance and nature of the various market areas, because, as has just been shown,

the sulfuric acid plants vary enormously in size and character, being mostly small chamber plants producing 50° Bé. acid in the South and large contact plants producing oil of vitriol and oleum in the North and the far West, as is evident from the first two columns in Table 36. These show that in

TABLE 36

SULFURIC ACID PLANTS AND CONSUMPTION, BY STATES, 1929*

State	Plants[a]		Percentage of Total Consumption, Estimated	Percentage of Total Production		Remarks
	Chamber	Contact		Actual[b]	Estimated	
Area A[a], Total	44	19	33.00	35		
Massachusetts	6	2	2.32	...	3.53	Surplus to New England
Connecticut	2	..	3.05	...	....	Deficit
New York (City)	2	..	5.59[c]	...	0.57[c]	Deficit
New Jersey	15	8	8.34	13.7	11.98	Surplus to New York
Pennsylvania (Philadelphia)	9	5	6.79[d]	6.6[d]	6.70[d]	Balance
Maryland	10	3	6.39	8.9	8.70	Surplus to Pennsylvania and Area C
Delaware	..	1	0.12	...	....	
Area B[a], Total	28	11	17.00	15		
New York (Buffalo)	3	2	1.70[c]	...	1.70[c]	Balance
Pennsylvania (Pittsburgh)	7	4	4.00[d]	5.0[d]	5.00[d]	Surplus to Ohio
Ohio	16	3	8.43	7.3	7.20	Deficit
Michigan	2	2	2.59	...	0.88	Deficit
Area C[a], Total	102	5	22.00	15		
Kentucky	..	1	0.28	...	....	
West Virginia	2	..	1.31	...	....	
Virginia	8	1	3.51	2.5	2.90	Large deficit supplied mainly from Tennessee
South Carolina	13	..	2.92	1.3	2.15	
North Carolina	17	..	3 31	1.6	2.39	
Georgia	32	..	4.87	2.9	3.34	
Florida	5	1	1.52	...	0.86	
Alabama	14	1	3.66	1.6	2.35	
Mississippi	7	1	0.57	...	0.76	
Arkansas	4	..	0.10	...	0.51	

TABLE 36—(*Continued*)

State	Plants[a] Chamber	Plants[a] Contact	Percentage of Total Consumption, Estimated	Percentage of Total Production Actual[b]	Percentage of Total Production Estimated	Remarks
Area D[a], Total	8	1	1.00	8		
Tennessee	8	1	1.20	8.9	7.83	Large surplus sold to Area C
Area E[a], Total	16	10	13.00	13		
Illinois	13	4	5.71	9.4	8.20	Illinois sells to the rest of the area, especially Indiana
Indiana	2	2	4.73	...	1.89	
Wisconsin	1	3	0.75	...	0.25	
Missouri	..	1	0.98	...	....	
Area F[a], Total	11	10	8.00	8		
Kansas	1	..	1.10	...	1.02	Reclaimed acid supplies from Oklahoma
Oklahoma	1	2	0.07	...	1.02	
Louisiana	6	3	2.09	1.8	1.26	
Texas	3	5	4.56	3.8	3.91	
Area G[a], Total	11	11	6.00	6		
California	6	6	4.55	...	4.70	
Colorado	1	2	0.48	...	0.51	
Arizona	1	1	0.22	...	....	Balance
Utah	1	1	0.10	...	....	
Montana	1	..	0.05	...	....	
Washington	1	1	0.19	...	....	
				Undistributed 8.91		
Total in the United States	220	67	100.00		100.00	

* Rearranged, adapted, and taken, except where otherwise indicated, from editorial estimates, *Chemical and Metallurgical Engineering* (January 1930), Vol. XXXVII, No. 1, p. 4.

[a] Division of states into areas and computation of area totals are not in the original: It gives the states in alphabetical order, not as here presented in geographical order from North and East to South and West. It lists as separate plants chamber and contact units when they are in operation in the same plant. It recommends these production and consumption percentages only for purposes of comparison and warns that, while the rough calculations here reproduced are believed accurate within 10 or 15 per cent, reliable sources of data are not available. It lumps together in the undistributed total the production of all states having two sulfuric acid plants or less.

[b] Census figures not available when estimate was made and inserted here as a check.

[c] Divided arbitrarily between area around New York City and that around Buffalo.

[d] Divided arbitrarily between area around Philadelphia and that around Pittsburgh. Total is that of census; see Table 19.

1929 the South had nearly one-half the total number of chamber plants in the United States—102 out of 220—but only 5 out of a total of 67 contact acid plants.

The division of the United States into areas in Figure 12 follows that of the Tables 35 and 36. They represent different sets of competitive conditions. In Area A is concentrated more than a third of the sulfuric acid production and consumption in the United States. Massachusetts, New Jersey, and Pennsylvania manufacture large quantities of oleum and market much more of it than of any other strength, because they sell to the large dyestuffs, pharmaceutical, lacquer, textile, explosives, pyroxylin plastics, petroleum, refrigeration, food-preservation, and general chemical industries of those metropolitan districts. The concentration of Maryland on the sale of 50° Bé. acid is due to the momentum of the early start in fertilizer manufacture there.

In Area B the main consumers of sulfuric acid are the steel and the automobile industries, the former for the process of pickling—that is, removing impurities prior to tinning, enameling, or galvanizing—the latter for a variety of purposes already mentioned. Around Buffalo there is concentrated a considerable amount of dyestuffs manufacture. The astonishingly large amount of 60° Bé. acid sold in Pennsylvania comes mostly from the portion of it included in Area B, representing in part by-product acid from zinc smelters and in part the influence of the glass industry, which demands large quantities of niter cake as one of its raw materials.

In Areas C and D have been grouped together those states which produce weaker strengths of sulfuric acid and usually consume it in order to manufacture fertilizers in distributing centers for farm supplies. Over a considerable portion of this area sulfuric acid from Tennessee is being marketed either directly in the form of 60° Bé. acid or indirectly in the form of superphosphates.

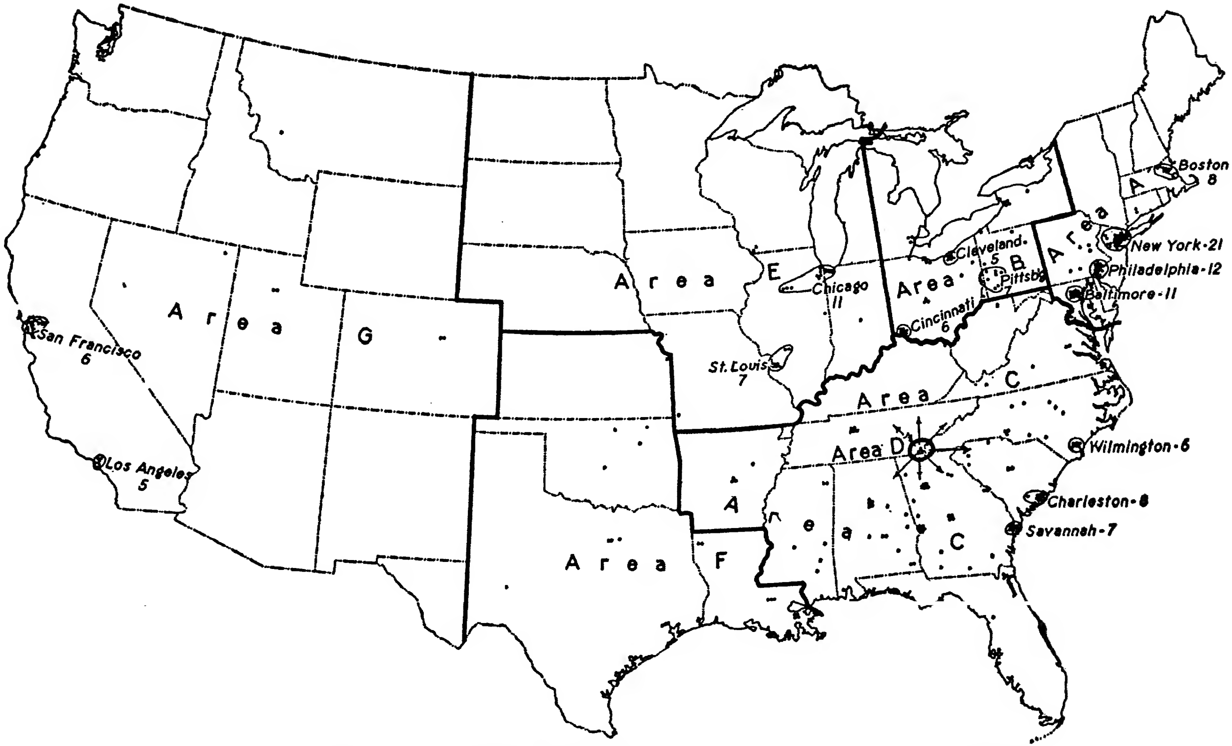


FIG 12.—Distribution of sulfuric acid plants in 1929. For source of data, see Table 37.

In Area E are located the plants, especially in the vicinity of St. Louis, which market sulfuric acid in connection with the roasting of zinc blende, much of it again being sold to producers of fertilizers and to supply the metropolitan needs of St. Louis. A small amount of acid in Illinois and Indiana is also obtained from marcasite (iron pyrites) produced at coal washeries[3] and from lead concentrates produced by lead smelters.

Area F has developed very rapidly since the World War. It is the center of the petroleum industry and consequently of the producing and selling of reclaimed acid.

The mountainous portions of Area G are sometimes regarded as a region of considerable potentiality for sulfuric acid production. Practically all of the commercially important ores of copper, gold, silver, zinc, and lead are sulfides which when roasted yield injurious sulfurous gases. Copper smelters in particular, notably in Montana and Arizona, have "erected acid plants to mitigate this smoke nuisance, and to supply their acid requirements for the hydrometallurgy of copper and zinc ores, and for the concentrating mills using the flotation process."[4] The acid made by the Calumet and Arizona Mining Company is practically all used for leaching carbonate copper ores at Ajo, Arizona. The Anaconda Copper Mining Company uses it also to leach mill tailings and zinc ores. But in recent years the acid-flotation process has been steadily losing ground to the alkali-flotation process. In short, except for explosives, there has not yet been developed an industrial, agricultural, or urban market for sulfuric acid in the intermountain area.

[3] H. McCormack, "Modern Plants in Illinois and Indiana Would Improve Efficiency of the Chemical Industry," *Chemical and Metallurgical Engineering* (January 1927), Vol. XXXIV, No. 1, p. 19.

[4] Stuart Croasdale, "Rocky Mountain Region Holds Undeveloped Resources of Vast Extent," *Chemical and Metallurgical Engineering* (January 1927), Vol. XXXIV, No. 1, p. 30.

On the Pacific Coast, however, there has been rapid progress. The fabulous growth of the petroleum industry there, the highly intensive type of horticultural cultivation of fruits and vegetables, and the commercial chemical needs of such rapidly growing metropolitan areas as San Francisco and Los Angeles all have contributed toward stimulating a vigorous growth of the manufacture of sulfuric acid, especially in the form of oil of vitriol and oleum.

SUMMARY

The market for sulfuric acid thus proves to be not one market but a congeries of markets loosely tied together by such common factors as the price of sulfur and pyrites; the competition in finished products such as fertilizers, dyestuffs, and technical specialties; the impact of general business and credit conditions; the spread of scientific knowledge and diffusion of cost-lowering techniques through establishment of branch plants; the increase in chemically trained personnel; and the increasing awareness and alertness of capital to chemical opportunities. In general, plants are established at points of consumption, the heavy expense and risk of haulage giving them a margin of protection so far as sulfuric acid is concerned though not keeping out the items it produces if they are valuable and easy to transport. The type of plant, and particularly the strength of acid produced, except in the cases of by-product acid from zinc and copper smelters and reclaimed acid, depends almost wholly on demand. Its volume practically determines the size of the plant. Therefore, taking the United States as a whole, we find wide though decreasing diversity in prices, a similarly wide diversity in the size of establishment, diametrically opposed policies with reference to marketing or consuming the product, and great differences in the magnitude, character, and direction of the competitive forces of demand and supply all affecting produc-

tion, pricing, and sales policies. Demand and absolute advantage or legal necessity in processing raw materials have been determinative. Costs of other factors of production—labor, capital, and management—seem to have been of secondary importance. Not the theoretical tools of international trade but those of monopolistic competition seem to be operating in interarea competition in the sulfuric acid industry.

TABLE 37

LOCATION OF SULFURIC ACID PLANTS IN THE UNITED STATES, 1930*

Company	Location	Type: Chamber	Type: Contact
Alabama, Total		14	1
American Agricultural Chemical Co.	Montgomery	X	..
duPont de Nemours & Co., E.I.	Mineral Springs	..	X
Farmers' Fertilizer Co.	Montgomery	X	..
Home Guano Co.	Dothan	X	..
Jefferson Fertilizer Co.	Bessemer	X	..
Planters' Chemical and Oil Co.	Talladega	X	..
Roanoke Guano Co.	Roanoke	X	..
Royster Guano Co., F. S.	Birmingham	X	..
Standard Chemical Co.	Troy	X	..
Steel Cities Chemical Co.	Ensley	X	..
Virginia Carolina Chemical Co.	Birmingham	X	..
	Dothan	X	..
	Mobile	X	..
	Opelika	X	..
	Selma	X	..
Arizona, Total		1	1
Apache Powder Co.	Douglas	..	X
Calumet and Arizona Mining Co.	Douglas	X	..
Arkansas, Total		4	..
Arkansas Fertilizer Co.	Little Rock	X	..
Commercial Acid Co.	Augusta	X	..
Ellory-Davis Corp.	Little Rock	X	..
Southern Acid and Sulphur Co.	Little Rock	X	..
California, Total		6	6
American Agricultural Chemical Co.	Los Angeles	X	..
Barbour Chemical Works	Melrose	X	..
Dominguez Chemical Co.	Dominguez		X

* *Chemical and Metallurgical Engineering* (January 1930), Vol. XXXVII, No. 1, pp. 50–51.

TABLE 37—(*Continued*)

Company	Location	Type: Chamber	Type: Contact
General Chemical Co.	Bay Point		X
	El Segundo		X
Hercules Powder Co. .	Pinole (not operating)		X
Mountain Copper Co.	Martinez	X	..
Stauffer Chemical Co.	Los Angeles	X	X
	San Francisco	X	..
	Stege	X	X
Colorado, Total			2
du Pont de Nemours & Co., E. I. ...	Louviers (not operating)		X
General Chemical Co.	Denver		X
Western Chemical Mfg. Co.	Denver		..
Connecticut, Total		2	..
Kalbfleisch Corporation .	Waterbury	X	..
Naugatuck Chemical Co.	Naugatuck	X	..
Delaware			
General Chemical Co.	Claymont		X
Florida, Total		5	1
American Agricultural Chemical Co.	Pensacola	X	..
American Cyanamid Co.	Tampa (building)	..	X
Armour Fertilizer Works.........	Jacksonville	X	..
Barker Chemical Co.	Dunnellon	X	..
Painter Fertilizer Co., E.O.	Jacksonville	X	..
Wilson & Toomer Fertilizer Co. ..	Jacksonville	X	..
Georgia, Total		32	..
American Agricultural Chemical Co.	Savannah .	X	..
Armour Fertilizer Works...........	Atlanta ...	X	..
	Columbus .	X	..
Blackshear Mfg. Co.	Blackshear	X	..
Cotton States Fertilizer Co.	Macon	X	..
Empire State Fertilizer Co.	Athens	X	..
Furman Fertilizer Works........	East Point	X	..
Georgia Fertilizer Co.	Valdosta ..	X	..
Home Guano Co.	Columbus .	X	..
International Agricultural Corp.	Columbus .	X	..
McCabe Chemical Co.	Macon	X	..
Mandeville Mills	Carrollton	X	..
Morris Fertilizer Works	Atlanta ...	X	..
Mutual Fertilizer Co.	Savannah .	X	..
Pelham Phosphate Co.	Pelham ...	X	..
Phosphate Mining Co.	Savannah .	X	

TABLE 37—(*Continued*)

Company	Location	Type: Chamber	Type: Contact
Reliance Fertilizer Co.	Savannah	X	..
Royster Guano Co., F.S.	Macon	X	..
Savannah Guano Co.	Savannah	X	..
Southern Fertilizer and Chemical Co.	Savannah	X	..
Southern States Phosphate Co.	Augusta	X	..
Southern Sulphur Oil Co.	Athens	X	..
Southern Sulphur Ore Co.	Columbus	X	..
Swift Fertilizer Co.	Atlanta	X	..
Tennessee Chemical Co.	Albany	X	..
Trout Co.	Lagrange	X	..
Virginia Carolina Chemical Co.	Atlanta	X	..
	Augusta	X	..
	Columbus	X	..
	Macon	X	..
	Rome	X	..
	Savannah	X	..
Illinois, Total		13	4
American Smelting and Refining Co.	East St. Louis	X	..
American Zinc, Lead, and Smelting Co.	East St. Louis	X	..
	Hillsboro	X	..
Anaconda Copper Mining Co.	Chicago Heights	X	..
Armour Fertilizer Works	Chicago Heights	X	..
Central Chemical Co.	West Hammond	X	..
Commercial Acid Co.	East St. Louis	X	..
Eagle-Picher Zinc Co.	Hillsboro (not operating)		X
General Chemical Co.	South Chicago		X
Hegeler Zinc Co.	Danville	X	
Illinois Zinc Co.	Peru	X	
Lanyon Zinc and Acid Co., Robert	Hillsboro	X	
Matthiessen and Hegeler Zinc Co.	La Salle	X	
Monsanto Chemical Works	Monsanto	X	X
New Jersey Zinc Co.	Depue		X
Victor Chemical Works	Chicago Heights	X	..
Indiana, Total		2	2
Grasselli Chemical Co.	Grasselli	X	X
Rauh & Sons Fertilizer Co.	Indianapolis	X	..
Stauffer Chemical Co.	Hammond	..	X
Kansas		..	..
National Zinc Co.	Argentine	X	..
Kentucky		..	..
Grasselli Chemical Co.	Wurtland		X

TABLE 37—(*Continued*)

Company	Location	Type: Chamber	Type: Contact
Louisiana, Total			3
Armour Fertilizer Works...........	New Orleans		..
Louisiana Chemical Co.	Baton Rouge		X
Planters' Fertilizer and Chemical Co.	New Orleans		..
Southern Acid and Sulphur Co.	Bossier City		X
Stauffer Chemical Co.	Baton Rouge	X	..
Swift Fertilizer Co.	New Orleans	X	..
Texas Chemical Co.	Baton Rouge	..	X
Union Seed and Fertilizer Co.	Gretna	X	..
Virginia-Carolina Chemical Co.	Shreveport ..	X	..
Maryland, Total		10	3
American Agricultural Chemical Co.	Baltimore ...	X	..
Baugh Chemical Co.	Baltimore ...	X	..
Davison Chemical Co.	Baltimore ...	X	X
Griffith-Boyd Co.	Baltimore ...	X	..
Lancaster Chemical Co.	Perryville ..	X	..
Mutual Chemical Co.	Baltimore ..	X	..
Naval Proving Ground	Indian Head	..	X
Raisin Monumental Co.	Baltimore ..	X	..
Royster Guano Co., F. S.	Baltimore ..	X	..
Standard Wholesale Phosphate & Acid Works	Baltimore	X	X
Virginia-Carolina Chemical Co. .	Baltimore	X	..
Massachusetts, Total		6	2
American Agricultural Chemical Co.	North Weymouth	X	..
Atlantic Chemical Co.	Lowell	X	..
Avery Chemical Co.	Tewksbury	X	..
Lowell Fertilizer Co.	Lowell	X	..
Merrimac Chemical Co.	Everett	X	X
	Woburn	X	X
Michigan, Total		2	2
American Agricultural Chemical Co	Detroit ...	X	..
Cleveland Cliffs Iron Co.	Marquette	X	..
Detroit Chemical Works.........	Detroit ...		X
Grasselli Chemical Co.	Ecorse		X
Mississippi, Total		7	
Davison-Gulfport Fertilizer Co. .	Gulfport	X	
International Agricultural Corp.	Tupelo	X	
Jackson Fertilizer Co.	Jackson	X	
Laurel Oil and Fertilizer Co.	Laurel	X	
Meridian Fertilizer Factory.......	Meridian	X	
	Hattiesburg ...	X	
Tupelo Agricultural Chemical Co.	Tupelo	X	

TABLE 37—(*Continued*)

Company	Location	Type: Chamber	Type: Contact
Missouri		..	..
Atlas Powder Co.	Atlas	..	X
Montana		..	..
Anaconda Copper Mining Co.	Anaconda	X	..
New Jersey, Total....................		15	8
American Smelting and Refining Co.	Maurer	X	..
American Agricultural Chemical Co.	Carteret	X	..
	Chrome	X	..
American Cyanamid Co.	Warners	X	X
Armour Fertilizer Works...........	Carteret	X	..
Atlas Powder Co.	Hopatcong	..	X
Calco Chemical Co.	Bound Brook	X	X
du Pont de Nemours & Co., E. I.	Deepwater	..	X
General Chemical Co.	Edgewater	X	X
Grasselli Chemical Co.	Grasselli	X	X
	Newark	X	..
	Paulsboro	X	..
Hercules Powder Co.	Kenvil	..	X
	Parlin	..	X
Kalbfleisch Corp.	Elizabeth	X	..
King Chemical Co.	Bound Brook	X	..
Mutual Chemical Co. ...	Jersey City	X	..
Standard Oil Co. (N.J.).	Bayonne (not operating)	X	..
Thomas & Sons, I.P.	Paulsboro (not operating)	X	..
New York, Total		5	2
American Agricultural Chemical Co.	Buffalo ...	X	..
Eastman Kodak Co.	Rochester	..	X
General Chemical Co.	Buffalo ...	X	X
(Contact Process Co. Division) ...	Buffalo ...	X	..
Kalbfleisch Corp.	Brooklyn .	X	..
Robinson Brothers Co.	Brooklyn .	X	..
North Carolina, Total		17	..
Acme Mfg. Co.	Wilmington	X	..
American Agricultural Chemical Co.	Wilmington	X	..
	Columbia ..	X	..
Armour Fertilizer Works...........	Greensboro .	X	..
	Wilmington	X	..
Caraleigh Phosphate and Fertilizer Works	Raleigh	X	..
Dixie Guano Co.	Laurinburg	X	..

TABLE 37—(*Continued*)

Company	Location	Type: Chamber	Type: Contact
McCabe Chemical Co.	Charlotte	X	..
Merchants' Feed and Phosphate Co.	Charlotte	X	..
Swift Fertilizer Co.	Wilmington	X	..
Virginia-Carolina Chemical Co.	Charlotte	X	..
	Durham	X	..
	Navassa	X	..
	Selma	X	..
	Wadesboro	X	..
	Wilmington	X	..
	Winston Salem.	X	..
Ohio, Total		16	3
American Agricultural Chemical Co.	Cincinnati	X	..
	Cleveland	X	..
American Steel and Wire Co.	Cleveland	X	..
Armour Fertilizer Works	Cincinnati	X	..
	Sandusky	X	..
Farmers' Fertilizer Co.	Columbus	X	..
Federal Chemical Co.	Columbus	X	..
General Chemical Co.	Cleveland	..	X
Grasselli Chemical Co.	Canton	X	..
	Cleveland	X	X
	Lockland	X	..
	Niles	X	..
	Toledo	..	X
Jarecki Chemical Co.	Cincinnati	X	..
St. Bernard Acid Works	St. Bernard	X	..
Smith Agricultural Chemical Co.	Columbus	X	..
Virginia-Carolina Chemical Co.	Cincinnati	X	..
	Sandusky	X	..
Oklahoma, Total		1	2
Mid Continental Chemical Co.	Sand Springs	X	..
National Zinc Co.	Bartlesville	..	X
Ozark Chemical Co.	Ponca City	..	X
Pennsylvania, Total		17	8
American Alkali and Acid Co.	Bradford	X	..
American Sheet and Tin Plate Co.	Vandergrift	X	..
American Steel and Wire Co.	Donora	X	..
American Zinc and Chemical Co.	Langeloth	X	..
Atlas Powder Co.	Tamaqua	..	X
General Chemical Co.	Newell	..	X
Grasselli Chemical Co.	Beaver Falls	X	..
	New Castle	X	..
	Philadelphia	X	X

TABLE 37—(*Continued*)

Company	Location	Type: Chamber	Type: Contact
Hercules Powder Co.	Emporium		X
Kalbfleisch Corp.	Erie	X	..
Lancaster Chemical Co.	Lancaster	X	..
Lenning & Co., Charles	Philadelphia	X	..
Merck & Co.	Philadelphia	X	..
New Jersey Zinc Co.	Palmerton		X
Pennsylvania Salt Mfg. Co.	Natrona	X	X
	Philadelphia	X	X
Powers, Weightman & Rosengarten	Philadelphia	X	..
Trojan Powder Co.	Seiple		X
Tunnell & Co., F. W.	Philadelphia	X	..
York Chemical Co.	York	X	..
United Gas Improvement Co.	Point Breeze (Philadelphia)		..
South Carolina, Total		13	..
American Agricultural Chemical Co.	Charleston	X	..
	Columbia	X	..
Anderson Fertilizer Works	Anderson	X	..
Etiwan Fertilizer Co.	Charleston	X	..
Maybank Fertilizer Co.	Charleston	X	..
Merchants' Fertilizer and Phosphate Co.	Charleston		..
Planters' Fertilizer and Phosphate Co.	Charleston	X	..
Read Fertilizer Co.	Charleston	X	..
Royster Guano Co., F. X.	Columbia	X	..
Virgina-Carolina Chemical Co.	Blacksburg	X	..
	Charleston	X	..
	Greenville	X	..
	Pon Pon	X	..
Tennessee, Total		8	1
Armour Fertilizer Works	Nashville	X	..
Ducktown Chemical and Iron Co.	Isabella	X	X
Federal Chemical Co.	Nashville	X	..
Kalbfleisch Corp.	Nashville	X	..
Read Phosphate Co.	Nashville	X	..
Tennessee Copper and Chemical Co.	Copper Hill	X	..
Victor Chemical Works	Nashville	X	..
Virginia-Carolina Chemical Co.	Memphis	X	..
Texas, Total		3	5
Armour Fertilizer Works	Houston	X	..
Gulf Refining Co.	Port Arthur		X
Southern Acid and Sulphur Co.	Port Arthur		X

TABLE 37—(*Concluded*)

Company	Location	Type: Chamber	Type: Contact
Sugarland Mfg. Co. .	Sugarland ..	X	
Texas Chemical Co. .	Fort Worth	..	X
	Houston ...	..	X
United Chemical Co.	Dallas	X	..
	Fort Worth	..	X
Utah, Total		1	1
Garfield Chemical Co.	Garfield	X	..
Hercules Powder Co. .	Bacchus	..	X
Virginia, Total		8	1
American Agricultural Chemical Co.	Alexandria ...	X	..
General Chemical Co.	Pulaski	..	X
Richmond Guano Co.	Richmond	X	..
Robertson Chemical Corp.	Norfolk	X	..
Royster Guano Co., F. S.	Norfolk	X	..
Virginia-Carolina Chemical Co.	Lynchburg ...	X	..
	Pinners Point	X	..
	Portsmouth .	X	..
	Richmond	X	..
Washington		..	..
du Pont de Nemours & Co., E. I.	du Pont	X	X
West Virginia, Total		2	..
Fairmont Chemical Co.	Fairmont ..	X	..
United Zinc Smelting Corp.	Moundsville	X	..
Wisconsin, Total		1	3
du Pont de Nemours & Co., E. I. ...	Barksdale	X	X
National Zinc Ore Separating Co.	Cuba City	..	X
New Jersey Zinc Co.	Mineral Point		X

IX. Joint-Cost Competition

Competition between individual companies in the sulfuric acid industry, complex as it is because of the factors mentioned thus far, namely, interprocess, inter-raw-material, interindustry and interarea competition, is made considerably more complex by a variety of joint-cost and joint-product relationships, some unavoidable, others optional. Those that are unavoidable arise from the technological fact that chemical transformations usually mean splitting up material into two or more products—as, for example, pyrites into iron and sulfur dioxide—or they mean interaction of two or more materials to produce two or more products one of which is the product primarily desired, the other being joint product, by-product, or waste—as, for example, the "potting" of niter, that is, letting sulfuric acid act on the nitrate to give the desired nitrous oxide (whose catalytic action is wanted in the lead chamber) and also a by-product niter cake.

These secondary, derivative, or waste gases, liquids, or solids do not necessarily have to be processed. They can be thrown away. And in the absence of governmental regulations on waste disposal, they *will* be wasted unless there emerges a chance to profit from adding to yields per unit of cost. If the substance can be made to contribute a bit toward lowering the expenses of putting out the main product, diverse measures will be taken. If the unutilized material can be packaged and sold as such, that is done. Sometimes uses can be found for it by research and a demand created by advertising. Frequently, however, it will have to be processed or compounded, operations likely to generate new by-products, and so on. Generally there will be different solutions by different companies, so that each will have a differently constituted flow of products and a special set of markets.

The considerations of policy or business strategy that lead to the production of a variety of products are several. As I have stated elsewhere:

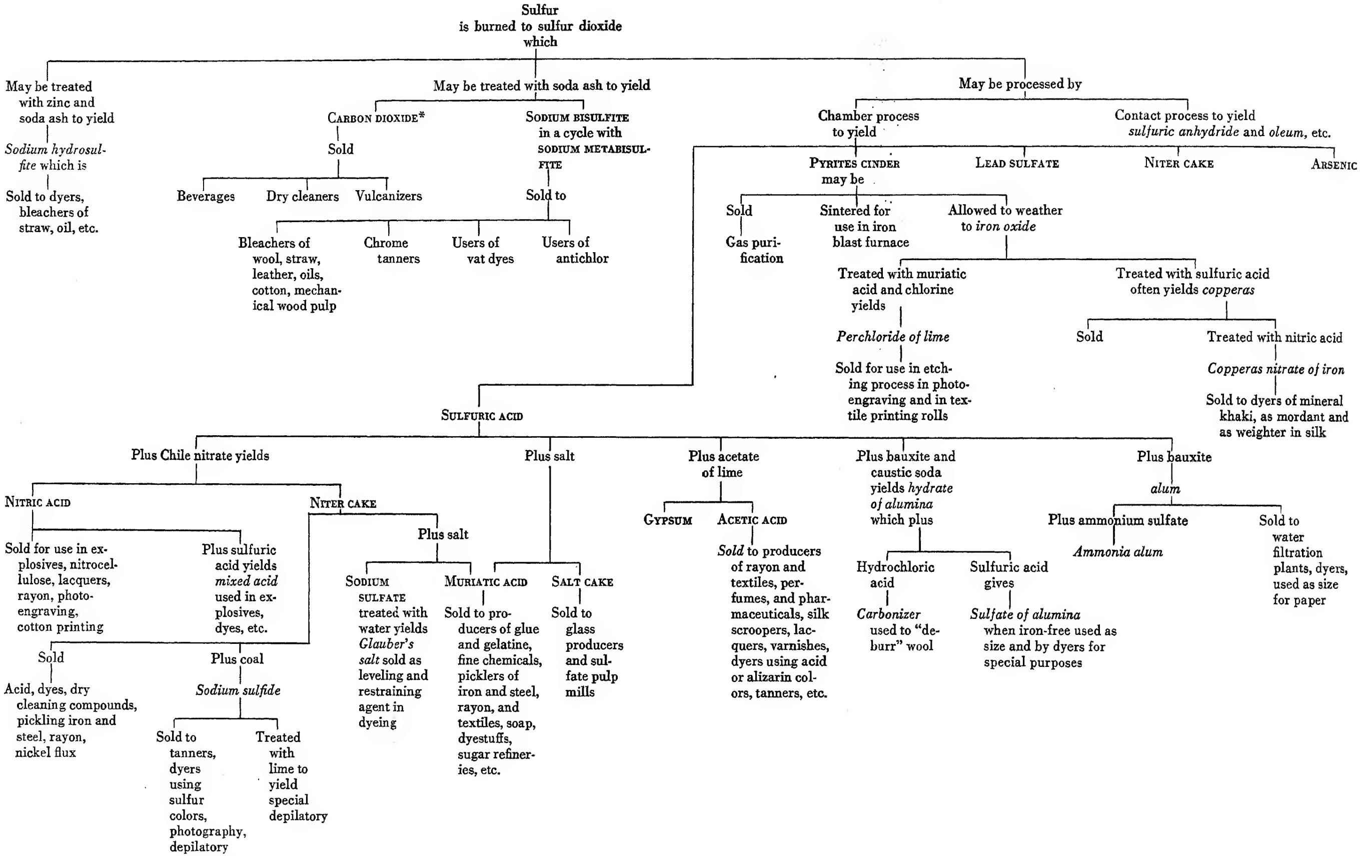
> Increasing experience in the production and sale of one chemical inevitably increases the ability to process and market other kinds. To retain the loyalty of the technical and sales personnel, to prevent them from getting too far away from the acme of their skill, and to retain whatever efficiency there may have been because of a favorable *esprit de corps* and happy collective adjustment to each other, chemical manufacturers ultimately develop a multipillared market which will consume a volume of product that is as steady as possible. Another reason is that much of the equipment, such as crushers, evaporators or tank cars can be used for many chemicals, and corrodes sometimes more rapidly standing idle than when used. . . . . The integration of industry is in part the effect of joint costs, especially in so far as markets are coalesced and greater efficiency in the time of delivery and in the adequacy of supply of raw materials is promoted. Thus the manufacturers who make their living from the sulphuric acid business have generally turned to the production of alum, acetic acid, hydrochloric acid, nitric acid, bisulphites and the like.[1]

In short, different fringe markets are developed in order to minimize discontinuity of operation and promote maximum utilization of the productive resources which the business has at its disposal.

JOINT PRODUCTS IN A TYPICAL PLANT

The phenomenon of joint costs does not show itself in its full complexity in all of the industries that produce sulfuric acid but only in the main industry. The large amount of sulfuric acid produced by fertilizer manufacturers, for example, is consumed directly, usually without any by-product problem of any significance. Similarly, the petroleum refineries have large plants producing nothing else than sulfuric acid, generally by the contact process, although at present

[1] T. J. Kreps, "Joint Costs in the Chemical Industry," *Quarterly Journal of Economics* (May 1930), Vol. XLIV, No. 3, p. 454.



* For significance of italics and small capitals, see text p. 171.

there are a number of individual plants in which the manufacture and sale of reclaimed acid presents a joint-cost problem of no small importance. Similarly the acid produced by zinc and copper smelters does not present the joint-cost problem in aggravated form. These industries, moreover, have already been dealt with in chapter vii on interindustry competition. But in that fraction of the total output which is marketed by the "chemicals not elsewhere classified" industry and especially by the sulfuric, nitric, and mixed acids industry, all of the characteristics of joint supply are illustrated in excellent fashion. It is upon that segment of the sulfuric acid trade that attention will be concentrated in this chapter.

An analysis of the operations of a typical plant in that industry shows that joint-cost considerations begin even with the initial process of burning sulfur to sulfur dioxide. For while the burner gas is usually processed by either the chamber method or the contact procedure, to make sulfuric acid, it may be used in other ways. Where there is a local textile demand for bleaching agents, antichlor, and dyes, for example, it is sometimes used to make such chemicals as sodium hydrosulfite and sodium bisulfite.

The overwhelmingly large proportion of the gas is, of course, used as a raw material for sulfuric acid, but this may be marketed as such or used to make other chemicals in the plant. Among the products so made are nitric, muriatic, and acetic acids, alum, and their derivatives and joint products. Some plants make ammonium sulfate, phosphoric-acid and sodium phosphates, oxalic, formic, and other organic acids, as well as dyes, pharmaceuticals, aromatic substances, and so on.

The simplest case is that of a sulfuric acid plant of moderate size in the sulfuric, nitric, and mixed acids industry. Its operations are shown in the accompanying diagram. Notice, first, that only eight materials need to be bought:

sulfur, pyrites, zinc, soda ash, Chile nitrate, salt, acetate of lime, and bauxite. On the other hand, the number of products sold may be more than three times as great and the markets for which they are produced range from small specialized trades such as photoengraving to gigantic industries such as textiles and steel. The particular business whose operations are charted in the diagram is obviously one which has directed its energies toward supplying the variety of chemical needs of the textile and paper industries.

A further indication of the pull exerted by the particular composite of market demand in which a sulfuric acid plant finds itself is constituted by the number of instances of joint demand shown in the diagram. Suppose the wool manufacturers, for example, need a carbonizer to remove straw, burrs, and other vegetable matter from wool. While under certain conditions sulfuric acid will do the trick, under other circumstances aluminum chloride is more suitable. To meet the needs of this regular acid customer, the sulfuric acid producer often agrees to supply the aluminum chloride and thereby pledges himself to buy salt, bauxite, and caustic soda and to make hydrochloric acid (using sulfuric acid in the process).

Similarly the paper mills need a substance in addition to bleaching powder to bleach the wood pulp. That substance being alum, the sulfuric acid producer buys alumina or bauxite and makes it. The paper mill uses it, finds it works excellently, alum forming aluminum hypochlorite with bleaching-powder solutions; but when the pulp has been bleached white the process needs to be stopped or the fiber will be chlorinated and the yellowish color taken up again. How stop the chlorination, the paper mill customer asks the sulfuric acid producer who sold him the alum. And the latter proceeds to make an antichlor, one which dovetails most closely with his operations, namely, sodium bisulfite. Con-

sequently he takes the sulfur dioxide direct from his burner, buys soda ash, and gets the desired antichlor, only to find himself faced with the problem—an unimportant one here, by chance—of getting rid of or using the carbon dioxide. Again the demand of his customers has led him into new fields of production and marketing.

Equally striking are the examples of substitutes. Notice, for example, the number of products which the sulfuric acid producer can offer to galvanizing, tinning, or enameling works to do the job of pickling the steel they use: sulfuric acid, niter cake, and muriatic acid. For the photoengraving trade he has nitric acid, perchloride of lime, and sodium sulfide. For the dyers he has sodium hydrosulfite, sodium bisulfite, copperas nitrate of iron, mixed acid, niter cake, sodium sulfate, acetic acid, and sulfate of alumina.

Most important of all are the many instances of joint costs and joint products. The products set in italics represent optional joint products, not all of which are compulsory yet some one of which is. Sulfur dioxide does not have to be treated with soda ash nor processed by the chamber or contact process, but if it *is produced* something will have to be done with it. The products set in small capitals represent cases of comparative technological rigidity. If the sulfuric acid producer decides to use his product in making nitric acid from sodium nitrate, he is bound to get niter cake as well. In some instances, by varying the pressure, temperature, concentration, and so on, he can alter somewhat the proportions so as to get more of the product he wants and less of that for which the market is slow, but not to the extent of eliminating one or the other entirely. Some by-product is unavoidable.

SULFURIC, NITRIC, AND MIXED ACIDS INDUSTRY

Belonging to the sulfuric acid industry in the strictest and narrowest sense are those producers who were first distin-

guished in the Census of Manufactures in 1905 as belonging to the "Sulphuric, Nitric, and Mixed Acids Industry." In 1929 the differentiation was dropped, the industry being placed with the "Chemicals not Elsewhere Classified" industry.

The available statistics for the industry therefore cover the period 1900 to 1927. In so far as the products are concerned, they are given in Table 38, below. The number of

TABLE 38

PRODUCTS OF THE "SULFURIC, NITRIC, AND MIXED ACIDS" INDUSTRY, 1899–1927*

Year	Number of Establishments	Thousands of Tons of Sulfuric Acid Produced	Value of All Products (*Thousands of dollars*)	Sulfuric Acid (*Thousands of dollars*)
1899.....	34	453	8,596	4,072
1904.....	32	467	9,053	4,286
1909.....	42	855	9,884	5,629
1914.....	32	1,359	15,215	9,045
1919.....	39	1,899	31,470	18,113
1921.....	36	1,523	21,463	14,406
1923.....	37	2,049	24,405	17,140
1925.....	36	2,165	23,307	16,021
1927.....	35	2,036	23,555	16,804

* Bureau of the Census reports on "Chemicals and Allied Products" in the censuses of manufacture for the years indicated.

establishments has remained roughly the same, but of course the membership has not. Several firms have at times probably been in and out of this enumeration, because a part of the shift is a matter of census definition. Between 1923 and 1925, for example, the figures show a net decrease of one establishment. Actually there was a gain of four establishments and a loss of five, three of the latter reporting products other than sulfuric, nitric, and mixed acids in 1925 as their

principal products and being accordingly transferred. One was idle during the year, and one had gone out of business.

For those firms which reported sulfuric, nitric, and mixed acids as constituting the leading sales item in their business (production may be an altogether different matter), the generalization seems warranted that the size of establishment has increased: in terms of tons of acid nearly fivefold, from 13,000 to 58,000 tons; in terms of value of product nearly threefold, from $253,000 to $701,000; and in terms of value of sulfuric acid sold about fourfold, from $120,000 to $509,000.

In 1925, of the 36 establishments reporting to the Bureau of the Census, 5 were located in Pennsylvania, 4 in California, 4 in New Jersey, 4 in Ohio, 3 in New York, 3 in Texas, 2 in Arkansas, 1 each in Alabama, Colorado, Connecticut, Illinois, Kansas, Louisiana, Oklahoma, Tennessee, Utah, Virginia, and Wisconsin. This has been approximately the geographical distribution throughout the period. In 1904, for example, there were 5 establishments in Pennsylvania, 4 in California, and 7 in New York. In nearly every case the plants are near the large centers of population and cater to the multitudinous demands of modern industrialism.

Throughout the period (consult Table 3, p. 40) the sulfuric, nitric, and mixed acids industry has produced sulfuric acid of higher average value per ton than any other branch of the business. While data do not exist to show precisely how it has specialized in the production of oleum, oil of vitriol, and acids of higher strengths, in short, how it has supplied the relatively expert technical service necessary to concentrate sulfuric acid to higher strengths and requisite to use the contact process for producing oleum, the detailed figures for 1905 given in Table 39 do indicate that even at that time three-fourths of the acid produced was of 66° Bé. grade or stronger.

TABLE 39

QUANTITIES AND GRADES OF ACID PRODUCED BY "SULFURIC, NITRIC, AND MIXED ACIDS" INDUSTRY IN 1905*

Item	Quantity in Tons	Value	Percentage of Total
Oleum	13,268	$ 361,018	8
66° Bé. acid	199,663	2,886,179	67
60° Bé. acid	13,634	121,432	3
50° Bé. acid	128,389	917,683	22
Total sulfuric acid	....	$4,276,312	100

* Taken from census of manufactures for 1905.

NITRIC ACID

The production of nitric acid by the industry was, of course, suggested by the very nature of the chamber process; for, as has been shown, the chemical reaction that occurs as a result of "potting" niter is identical with that used almost exclusively until recently (now ammonia is oxidized) to make nitric acid, namely, the action of sulfuric acid on Chile nitrate. Sulfuric acid producers, therefore, thoroughly familiar with the substance and its mode of manufacture, naturally stood ready to supply it to the trade as demand arose. Their experience in handling sulfuric acid provided excellent qualification for handling it; for it, too, is of such a highly corrosive nature as to have led Geber, the ninth-century chemist, to call it *aqua fortis*. It, too, must be shipped in glass or stoneware carboys. First made in 1834 by the firm of Carter and Scattergood in Philadelphia, about one-half or more of its manufacture has been concentrated in the state of New Jersey. It is likewise produced in many grades and is almost as widely used as sulfuric acid, being employed in 1926 to the extent of approximately 70 per cent in the manufacture of explosives such as TNT, picric acid, and nitroglycerine; 20 per cent for pyroxylin plastics and especially pyroxylin lacquers such as Duco; 5 per

cent for chemicals and dyes; and 5 per cent for all other uses such as electroplating, photoengraving, making nitrobenzol, Berlin Blue, and nitrate of iron (for dyeing silk black), and refining the precious metals.[2]

In making nitric acid the sulfuric acid producer encounters two typical problems. In the first place, he competes in part with his customers. Even in 1904, when the sulfuric, nitric, and mixed acids industry sold 15,153 tons of the stuff, worth $1,446,471, it sold only two-thirds of all that was sold (23,132 tons, worth $2,250,944) and less than one-third of the total (54,190 tons) produced. Most of it, in other words, was made by explosives manufacturers right on the spot, out in the waste areas where their plants are usually established. In recent years this has been even more true, as shown in Table 40.

Production by the sulfuric, nitric, and mixed acids industry has been but a small fraction of the total produced, and, while no figures are available later than 1919 on the amount of the product which it consumes in its own works, probably more than three-fourths of it (in 1919, 14,970 out of 18,831 tons) is used in further operations, notably in making sulfuric acid by the chamber process and in making mixed acids. The important industry producing nitric acid for the market is the "chemicals not elsewhere classified" industry. Today probably 90 per cent of the domestic production of nitric acid is obtained by the synthetic process, i.e., ammonia oxidation. The place of the sulfuric acid producer has become increasingly small.

The second problem which the sulfuric acid producer faces, whether or not he produces nitric acid for sale, is that of a by-product, sodium acid sulfate or niter cake. In the main it is a substitute for his main product, sulfuric acid, in

[2] William M. Rand, "Selling Nitric Acid to Many Industries," *Chemical and Metallurgical Engineering* (August 1926), Vol. XXXIII, No. 6, p. 488.

TABLE 40

INDUSTRIES PRODUCING NITRIC ACID, 1899–1935*

Year	Number of Establishments	Total Production (*Tons*)	For Sale		Produced by Explosives Industry (*Tons*)	Produced by "Chemicals not Elsewhere Classified" Industry (*Tons*)	Produced by Sulfuric, Nitric, and Mixed Acids Industry (*Tons*)
			Tons	Value in Thousands of Dollars			
1899......	..[a]	31,542	15,481	1,455	7,274	....[a]	10,201
1904......	..[a]	54,190	23,132	2,251	18,988	....[a]	15,153
1909......	25	68,717	13,663	1,357	31,484	....[a]	.....[a]
1914......	52	78,589	14,685	1,591	47,113	4,428[b]	9,794[b]
1919......	59	86,992	19,436	2,976	48,588	19,573	18,831
1921......	56	57,887	8,300	1,318	34,376	13,298	10,213
1923......	55	77,633[c]	21,759	2,741	65,595	33,602	13,919
1925......	53	80,443[c]	26,852	3,560	80,821	26,750	12,081
1927......	50	91,077[c]	28,706	3,560	79,867	28,910	13,214
1929......	49	143,454[c]	34,881[c]	3,495	105,781	54,472[c]	
1931......	43	117,240[c]	37,506[c]	1,800	......[a]	.....[a]	
1933......	34	100,414[c]	32,839[c]	2,969	......[a]	.....[a]	
1935......	28	122,596[c]	24,503[c]	2,142	......[a]	.....[a]	

* Bureau of Census reports on "Chemicals and Allied Products," in censuses of manufacture for the respective years.

[a] No data.

[b] Amount for sale.

[c] Basis 100 per cent nitric acid.

making hydrochloric acid, pickling metals, absorbing ammonia, and acidulating phosphate rock. As is shown in Table 41, the amounts produced in recent years have steadily dwindled. They have at no time been of primary importance. Production has, of course, been concentrated in the same states as has the production of nitric acid, in 1931 5 of the 28 producers being in Pennsylvania, 4 in New Jersey, 3 in Illinois, and 3 in Ohio.

The outstanding feature in Table 41 is the rapid decline in niter-cake production after 1927 accompanied by a price jump to levels three times as high in 1929 as in 1925. The reason is, of course, the introduction of the ammonia oxidation process; a sharp reduction in the price of nitric acid, but

no by-product niter cake, so that where sulfuric acid cannot be substituted for it, as in certain smelting operations, it has become a main product forthcoming only at higher prices.

TABLE 41

PRODUCTION AND SALES OF NITER CAKE, 1909–1935*

Census Year	Number of Establishments	Total Produced (*Tons*)	For Sale			Value of Nitric Acid per Ton
			Quantity (*Tons*)	Value	Value per Ton	
1909	24	......[a]	27,546	$ 53,693	$ 1.95	$ 99
1914	31	46,143	24,129	31,580	1.31	108
1919	38	97,836	81,170	281,476	3.47	153
1921	38	55,578	48,965	274,161	5.60	159
1923	45	154,087	129,447	587,897	4.54	126
1925	42	124,296	101,596	400,598	3.94	133
1927	38	153,615	120,506	625,049	5.19	124
1929	46	111,522	82,683	1,023,136	12.37	100
1931	28	35,680	30,661	563,872	18.39	48
1933	20	30,558	17,012	352,512	20.72	90
1935	16	27,933	18,585	342,132	18.41	87

* From Bureau of Census reports on "Chemicals and Allied Products" in censuses *of manufactures for the respective years.* [a] *No data.*

MIXED ACIDS

The use of mixed acid, that is, sulfuric and nitric acid mixed together in proportions varying with the requirements of the user, began with efforts to make nitrobenzene and picric acid. Its first real impetus, however, came in 1862 with the beginning of the commercial manufacture of nitroglycerine. No one knows who discovered that two substances so difficult to transport as sulfuric and nitric acids could when mixed together in highest concentration be shipped simply in old glycerin drums. But for years small users have obtained their mixed acid that way.

The amounts which have been produced by the sulfuric, nitric, and mixed acids industry are given in Table 42, below. They represent in recent years less than a third of the total

TABLE 42

PRODUCTION AND SALE OF MIXED ACIDS, 1899–1935*

Year	Number of Establishments	Total Production (*Tons*)	For Sale		Produced by Explosives Industry (*Tons*)	Produced by "Chemicals not Elsewhere Classified" Industry (*Tons*)	Produced by Sulfuric, Nitric, and Mixed Acids Industry (*Tons*)
			Tons	Value in Thousands of Dollars			
1899......	..[a]	......[a]	21,152	$1,110	.....[a]	.....[a]	21,150
1904......	..[a]	......[a]	32,665	1,957	.....[a]	.....[a]	21,406
1909......	14	......[a]	28,591	1,861	.....[a]	.....[a]	.....[a]
1914......	37	112,124	42,725	2,204	69,400	11,264[b]	23,616[b]
1919......	42	114,886	46,428	4,427	72,174	10,076	32,636
1921......	58	89,544	40,248	3,406	56,708	14,748	18,088
1923......	51	156,467	77,933	5,503	102,006	34,350	20,111
1925......	39	160,269	61,290	3,767	88,029	42,697	29,903
1927......	41	180,142	60,625	3,821	106,457	54,251	19,434
1929......	36	184,163	63,721	4,214	120,400	63,763	
1931......	27	101,707	37,586	1,800	.....[a]	.....[a]	
1933......	17	......[a]	41,962	1,883	.....[a]	.....[a]	
1935......	18	......[a]	46,074	2,105	.....[a]	.....[a]	

* Data compiled from Bureau of Census reports on "Chemicals and Allied Products" in censuses of manufactures for the respective years. [a] No data. [b] Amount for sale.

produced, though considerably more than half of the total for sale. The industry sells nearly all it produces, in 1919 consuming in its own operations only 2,973 tons or less than 10 per cent, as opposed to explosives manufacturers, who in that same year used 61,345 tons of their product, or more than 85 per cent. The manufacture of mixed acids is consequently also concentrated to the extent of 45 to 50 per cent of total production in the state of New Jersey.

In addition to the main products of the sulfuric, nitric, and mixed acids industry, the treatment of which has just been concluded, an ordinary plant will produce daily large quantities of substances which are dumped on waste piles near the plant. Some of them may have a limited use, as, for example, calcium sulfate for pigments, fillers, structural units, and the like; oxide of iron for pigments and gas purification; and pyrites cinder and sulfate of lead for smelting. Others, like

calcium carbonate, zinc carbonate, and bauxite waste mud, may accumulate for years.

CHEMICALS NOT ELSEWHERE CLASSIFIED

The line at which the boundaries of the sulfuric, nitric, and mixed acids industry merge into the "chemicals not elsewhere classified" industry is at best arbitrary and to a certain degree indistinguishable, particularly at the present time. At the beginning of the twentieth century the line of demarcation would certainly have been drawn at the point now reached in this discussion, that is, to include sulfuric acid, nitric acid, niter cake, and mixed acids (pyrites cinder and certain minor by-products have been ignored) but to exclude a wider range of products. Hence the Bureau of the Census delimited the field, and so it has been thus far defined here. With the passage of time, however, the process of taking on new products by producers of chemicals has made the manufacture of sulfuric acid a part of a much larger whole. Its production and sale today is geared and co-ordinated with production and marketing plans covering a much wider array of products. Consequently, in 1927 the Bureau of the Census abandoned the narrower definition of the field. That is what shall be done for the remainder of this chapter.

No attempt will be made to give a historical survey product by product, even of the thumbnail sort just utilized, for the various items whose production and sales have been tied up with the manufacture and marketing of sulfuric acid. But some sort of general picture is necessary to secure the elements of an understanding of the range of economic forces at work. The manner in which sulfuric acid producers branch out to produce other acids and salts is summarized in tabular form below. Space does not permit explaining in detail the manner in which the production of these various acids and salts is interrelated. Such would almost amount to writing a

text on industrial chemistry. Nor does it permit showing the number of alternative processes by which some of the products can be manufactured. Nor does it allow an enumeration of all of the markets in which each of the products may be sold. Such an enumeration would be repetitious, inasmuch as probably one-half of the items are or can be used in the textile industry, especially in dyeing operations. The list given below

A. ACIDS PRODUCED WITH THE AID OF SULFURIC ACID

Acid Set Free	Raw Material and Industry of Its Origin	Markets in Addition to Chemical Industry
	1. By direct action usually upon a natural salt or by-product of another process, liberating free acid	
Acetic	Acetates, wood distillation	Silk scrooping, paint, textiles
Carbolic	Coal-tar fraction after caustic extraction	Medicine, dyes, confectionery
Carbonic	Limestone or marble	
Chlorsulfonic	Chlorine and sulfuric acid	
Gallic	Tannic-acid-extracts industry	Tanning
Hydrochloric	Salt brines from mines and lakes	Textiles, steel, sugar, soap
Hydrocyanic and hydroferrocyanic	Gas, coke, and beet-sugar industries	Insecticide, metallurgy
Hydrofluoric	Fluorspar or cryolite	
Lactic	Lactates, dairy industry	
Nitric	Chile nitrate	Jewelry manufacturing
Oxalic	Sawdust	
Phosphoric	Bone ash or phosphate rock	Fertilizer
Valerianic	Fusel-oil-distillation industry with bichromate	
Vanadic	Carnotite ores, by-product radium industry	
	2. By action of sulfuric acid after a preliminary operation	
Chromic	Alkaline fusion chrome iron ore	
Silicic	Alkaline fusion of quartz	
H-acid	Sulphonation, nitration, reduction, fusion acidulation	Dyestuffs intermediate
Formic	Alkali heated under pressure with carbon monoxide or carbon dioxide	
Lactic, butyric, caproic, caprionic	Specific bacterial fermentation, starch, paste or sugar from corn, potato, molasses, etc.	

B. SALTS PRODUCED

Salt	Raw Material and Industry of Its Origin	Markets in Addition to Chemical Industry
Alum	Clay, bauxite, or cryolite	Water filtration, dyeing, paper making
Aluminum chloride	Bauxite, hydrochloric acid	Wool
Ammonium sulfate	Ammonia—gas industry	Fertilizer
Aqua ammonia	Gas-liquor—gas industry	Household use, refrigeration
Arsenates of lead, soda, etc.	By-product of burning pyrites, etc.	Insecticide
Copperas and nitrates of iron	By-product of many industries, especially "pickle liquors," etc.	Prussian blue, sewage disposal, ink
Glauber's salt	Salt cake	Dyeing
Muriate of tin crystals	Tin and hydrochloric acid	Silk, cotton
Nitrate of iron	Iron and nitric acid	Shoe stains, ink
Niter cake	By-product of manufacture of nitric acid	Smelting
Salt cake	By-product in manufacture of hydrochloric acid	Sulfate pulp, glass
Sodium bisulfite	Burner gases and soda ash	Chrome tanning
Sodium sulfide	Niter cake	Photography

merely shows a portion of the complications in planning purchases of raw materials, in co-ordinating production, and in making sales that characterize the modern sulfuric acid business.

Take, for example, two of the most important of the products listed—hydrochloric acid and its by-product, salt cake. For every three tons of the former two[3] tons of the latter are produced. There was a long period of time (from 1800 to 1910) in the history of the Leblanc soda industry when the relationship was decidedly the reverse. Salt cake was the main product and muriatic acid the corrosive waste gas that destroyed vegetation around the alkali plants, killed the fish in the streams, and corroded the ships at the wharves to such an

[3] William M. Rand, "Muriatic Acid—Staple Product of the Heavy Chemical Industry," *Chemical and Metallurgical Engineering* (April 1926), Vol. XXXIII, No. 4, p. 236.

extent as to lead to the enactment of a series of alkali acts. Now it is one of the most useful of chemicals and salt cake is a by-product. Large quantities are produced in the electrochemical industry with caustic soda as by-product.

The growth of the industry as shown in Table 43 has been substantial, though by no means rapid. The sales figure has ranged in the vicinity of three million dollars. Its uses parallel

TABLE 43

Muriatic Acid and By-Products, 1899–1935*

Year	Number of Establishments	Production (*Tons*)	For Sale (*Tons*)	Value in Thousands of Dollars	Salt Cake		Glauber's Salt	
					Production (*Tons*)	Sales in Thousands of Dollars	Production (*Tons*)	Sales in Thousands of Dollars
1899......	31	67,114	58,337	1,016	.....[a]	...[a]	....[a]	...[a]
1904......	36	94,269	87,260	1,613	38,244	...[a]	7,333	...[a]
1909......	38	122,367	101,607	1,758	.....[a]	...[a]	46,471	512
1914......	31	168,584	135,438	1,349	110,263	842	34,537[b]	428
1919......	38	221,749	150,090	4,312	179,003	1,930	42,206	864
1921......	37	157,571	96,100	2,778	131,701	2,046	52,041	1,289
1923......	39	218,521	155,814	3,102	187,064	2,972	66,192	1,521
1925......	37	227,800	155,019	2,976	189,293	2,339	57,622	1,265
1927......	40	224,596	162,442	3,016	208,565	2,787	53,420	1,082
1929......	33	81,307[c]	62,606[c]	3,195	206,612	2,015	61,953	1,112
1931......	..	54,889[c]	40,687[c]	2,422	119,399	1,528	48,899	847
1933......	36	62,628[c]	44,895[c]	2,387	114,610	1,471	39,804	586
1935......	32	87,090[c]	54,889[c]	3,048	169,167[d]	1,857	40,735	549

* Bureau of the Census reports on "Chemicals and Allied Products" in censuses of manufactures for the respective years.

[a] No data. [b] Amount for sale. [c] One hundred per cent strength.
[d] Includes natural salt made from brines.

those of sulfuric acid, being used in working metals, in the manufacture of gelatine, glue, dyestuffs, and soldering flux, in pickling iron, and in galvanizing by wire mills.

Its by-product, salt cake, formerly made in millions of tons as an intermediate product in the production of soda ash by the Leblanc process, is used to make kraft or sulfate pulp, plate and window glass, Glauber's salt, and anhydrous sodium

sulfate, as a diluent and assistant in the textile industry and as a flux in the glass and ceramics industry. As a by-product of hydrochloric and nitric acid its supply is diminishing rapidly, because both acids are produced by synthesis, and hydrochloric acid also results as a by-product from certain organic chlorinating processes. About 80 per cent of total production is marketed. It, too, comes from more than one industry, being separated in its natural state from brines in arid regions of Arizona, California, Nevada, Canada, and Chile. Its manufacture in Chile is a government monopoly. In California it is a by-product of potash and borax. It is the main product in Germany, where production, prices, and sales are controlled by a sulfate cartel. There it is manufactured in the potash industry and shipped to tidewater Louisiana for only $3.00 a ton. The American producer in Clarkdale, Arizona, on the other hand, has to pay a freight of $11.00 a ton to reach consuming coastal points in Louisiana and Washington. Such as these are the competitive forces which play upon the price, production, and sales policy of the one plant in Louisiana where it is the main product.

A bird's-eye view of some of the most important articles produced jointly with sulfuric acid and with its derivatives is afforded by Table 44. The first column compares in thousands of pounds the output of sulfuric acid with the other acids and salts. The figures show clearly the enormous preponderance of sulfuric acid. Even if placed on a monohydrate or 100 per cent basis, the production of sulfuric acid would still be over eight billion pounds, or more than ten times the next most bulky item, aluminum sulfate. When the value of the product sold is considered, however, notice that the figure for sulfuric acid is only four and one-half times as large as the next largest item, aluminum sulfate. The others in order of sales volume in 1929 were carbonic acid, acetic acid, mixed acid, arsenate of lead, nitric acid, and muriatic acid. It should be

TABLE 44

COMPARISON OF SUNDRY PRODUCTS OF THE SULFURIC ACID BUSINESS IN 1929*

Item	Production in Thousands of Pounds	Sales in Dollars	Number of Establishments	Geographical Distribution: Pennsylvania	New Jersey	California	Illinois	Ohio	Massachusetts	New York	Other States (*One each unless otherwise noted*)
Acids											
Acetic	72,731	6,890,411	17		3						Mich. 2, Ind., Md., N.Y., Tenn.
Carbonic	136,930	6,931,735	54		4						Tenn. 3, Tex. 3, Fla. 2, Ga. 2, Mo. 2
Chromic	4,212	710,272	8		3						Mo.
Hydrochloric	515,714	3,195,415			5						Conn. 2, Mich. 2, Ark., Del., La., Tex., Wash.
Mixed	368,326	4,214,433			8						Mo. 3, Ala. 2, Colo. 2, Mich. 2
Nitric		3,494,577			10						Mich. 3, Mo. 3, Ala. 2, Colo. 2, Conn. 2
Sulfuric		45,573,245	171	16	14						Ga. 18, S.C. 11, N.C. 9, Va. 9, Ala. 9, Tenn. 7
Tannic	1,449	503,567									Mo.
Alums											
Aluminum sulfate	689,924	8,038,730	27								Conn., Del., Ga., Ind., La., N.H., Tenn.
Ammonia alum	11,440	286,772									Delaware
Aluminum chloride	33,102	225,184									Conn., W.Va.
Ammonium sulfate (produced in chemicals industry)	11,853	240,391	10								Ky., La., Md., Mo., R.I., Tex., Va.
Arsenate of lead		3,523,427	20								Md. 2, Wash. 2, Ga., Ind., Mich.
Arsenate of calcium	33,064	1,859,735	16								Ga., Ind., Mich., Mo., Tenn.
Copperas	112,094	553,604	28								Ala. 2, Ind. 2, Conn., Mich., Mo.
Niter cake	223,044	1,023,036	46								Ga. 3, Mich. 3, Mo. 3, Tenn. 3, Conn. 2, N.C. 2
Salt cake	413,224	2,014,838	28								Conn. 2, Ariz., Ark., Del., Ind., Md., Mich., Tex.
Glauber's salt	123,906	1,112,267	20								Conn., Del., Iowa, Md.

* Department of Commerce, Bureau of the Census, *Fifteenth Census of the United States, Manufactures: 1929*, reprint on "Chemicals, Compressed and Liquefied Gases" (Washington, D.C., 1932).

remembered that in practically every figure a good deal of product is included that does not come from plants making sulfuric acid. That is, just as with nitric acid, hydrochloric acid, and salt cake, so here in the case of most of the items production comes from several industries.

A comparison of the number of establishments and their distribution by states brings the fact out clearly that by no means all plants produce all products but rather that some sulfuric acid producers choose to enter one field, others another. Only in the states of Pennsylvania, New Jersey, Massachusetts, Illinois, New York, and California does the sulfuric acid business put out its fullest multiplicity of products. In those states joint-cost relationships in the sulfuric acid business find their most varied and complete expression.

Table 44 indicates in the main those other products which are produced by sulfuric acid producers because of strong technological reasons. It shows the items that may be produced at the same plant, works, or establishment; but it does not begin to show the varied range of products put out by a single corporation.

Even costs at the plant or works are, however, hard to determine. To be sure, cost of production governs the collective normal price. But the complex of conditions shown by the respective demand schedules for the flows of products in their respective markets will determine the share of joint costs borne by each product. The cost accountant may allocate costs on the basis of relative sales values, but when a product goes through different processes each with a family of joint products of different constitution except with respect to the article in question, the cost figures arrived at by various plants are likely to be wide apart. Even for the same plant at different times variations in prices bring about variations in cost which are meaningless and misleading. Another method—treating the net yield value of joint or by-products as a reduc-

tion in the cost of the main product—is open to similar difficulties.

Many sulfuric acid producers have in their accounting procedure abandoned the effort to arrive at separate cost figures upon which to base price and manufacturing policy. They use their figures for purposes of internal control in order to get an unequivocal comparison of actual with attainable and past performance. They allot joint costs on the basis of some standard ratio, more or less arbitrarily chosen, yet sensitive to and accurately measuring the most important internal and external factors of variation.

The kind of procedure adopted by accountants in the industry is excellently shown in the example of the Hennepin Chemical Company.[4] It credits the main product for each by-product, but at an established standard rate. No effort is made to relate the standard rate to the selling price of the by-product. The value of the by-products is calculated at a standard rate and deducted from the cost of the raw materials which enter into the processes. All labor, power, supplies, repairs, and factory overhead are charged to the main product. This method, while arbitrary, gives the managers control over their operations. It makes the cost of the main products comparable from month to month, thus enabling the company to determine the profitability of their manufacture.

The distribution of expenditures is as follows: labor 10 per cent, material 39 per cent, power 12 per cent, supplies 2 per cent, repairs, 8 per cent, and overhead 29 per cent. Outlays for labor are relatively small, and expenses for materials, overhead, power, and repairs large. Much of the labor is not chargeable directly to product, except in some more or less arbitrary fashion. Thus the outlays in the service depart-

[4] The name is fictitious, but a real cost-accounting system is discussed. See T. H. Sanders, *Problems in Industrial Accounting* (A. W. Shaw Company, New York, 1923), pp. 416–28.

ments, such as the wages of janitors, watchmen, and clean-up and cooperage men can be imputed to specific units of output only with some degree of guessing. The burden is comprised of outlays for taxes, insurance, depreciation, works administration, and general expenses. This last item includes overhead expenses for blacksmith, carpenter, machine, plumbing, and paint shops, as well as outlays for trucking and teaming, for maintenance of plant locomotives, railways, tank cars, and cranes, and for the overhead on the cooperage and carboy shops. Laboratory expense constitutes 5 per cent of the burden, that is, more than 1½ per cent of the total production cost (which does not include interest or rent).

The foregoing points to the conclusion that joint-cost competition in the sulfuric acid business might easily lead to indiscriminate price cutting and chaos if the market mechanism and price fluctuations were relied upon as sole agencies of co-ordination. For, if producers are unable to know their costs, if the cost of costing is excessive, and if, as is the case, many of them do not even attempt to find particular costs for particular products but are quite happy when the receipts from the totality of their operations show a profit over the totality of their outlays, price quotations on individual articles upward or downward experience no curb from the operation of cost of production. Even at the lowest price some producers continue to produce sulfuric acid—those who are compelled to by injunction. Its highest price is, of course, limited by what the traffic will bear. In neither case, however, does the mechanism of the market act as a stabilizer. In short, in the absence of control, joint-cost competition in the sulfuric acid industry would be chaotic.

X. Intercompany Competition

The outstanding feature of intercompany competition in the sulfuric acid industry has been the control of risk through diversification. From small local enterprises making only a few chemicals, sulfuric acid concerns have become large national organizations making hundreds of products. In the words of one of the largest companies, the General Chemical Company, reviewing the twenty years of its growth between 1899 and 1919:

> When the company was formed it took over from the constituents the manufacture of only 15 different chemical products, but no one of the old concerns was making more than half a dozen, and some not so many. This company is now making nearly one hundred distinct commercial products besides many hundreds of fine and chemically pure products. The list is increasing, and with each increase the risks of the business are diminishing.[1]

Some of these risks have already been mentioned. Seasonal swings in particular items can be counterbalanced and a continuous flow of production secured. The multiplication of markets also emancipates the producer from sudden local changes in demand. Larger volume of production permits distribution of heavy overhead, particularly that involved in high obsolescence of chemical equipment and in salary cost of carrying skilled technical ability. Integration of operations from raw material to consumer frees the producer from contractual, bargaining, and other worries, and permits him to concentrate on technical efficiency in his plant and systematic development of his market. Innovations upsetting old technological least-cost equilibria bring him new markets or products for those they take away. Moreover, they affect only

[1] *The General Chemical Company after Twenty Years, 1899–1919* (privately printed, 1920), p. 16.

a part of his business, and with access already established to many markets and a plant equipped to put out a variety of products, he can more readily adjust his production and sales program to the innovation, being able to realize a maximum of salvage value from the old by turning it to other uses, and experiencing the minimum of difficulty in making profits from the new.

GROWTH IN SIZE OF ESTABLISHMENT

Individual plants have therefore tended to become larger, for when wastes or by-products are processed the amounts that used to be produced are often less than those permitting maximum efficiency of operation of a pendent industrial operation. Bids are made for the waste product of other firms, or the plant may experiment with increments in the total flow of its own output, thereby enlarging its whole process of production. The economies of joint-cost production thereby push the size of the establishment "much farther than is needed for the sake of efficiency in the main products alone. To make the weak links stronger the whole chain is magnified."[2]

The extent to which large-scale production has taken place in the "chemicals not elsewhere classified" industry, of which sulfuric acid is a part, is shown in Table 45, below. The number of establishments, while increasing from 1899 to 1919, and almost doubling in the period from 1914 to 1919, has diminished by more than a third since that time. The number of wage earners employed similarly reached a peak in 1919, and declined by nearly 20 per cent from 1919 to 1929, while the dollar value of products increased from 614 millions to 738 millions. When the notable price decline in chemicals from 1919 to 1929 is taken into account, the increase in volume of output is on the order of 70 per cent. The number

[2] J. M. Clark, *Economics of Overhead Costs* (Chicago, 1924), p. 102.

of wage earners per establishment, while varying, of course, with the state of business, undoubtedly doubled on the average between 1899 and 1929. On the other hand, the share of labor in the increment created by the manufacturing processes has been steadily less, diminishing from a third in 1899 to less

TABLE 45

GROWTH OF SIZE OF ESTABLISHMENT IN "CHEMICALS" INDUSTRY, 1899–1931*

Year	Number of Establishments	Wage Earners (Average for the Year)	Wage Earners per Establishment	Value Added by Manufacture (*Thousands of dollars*)	Wages (*Thousands of dollars*)	Wages as Percentage of Value Added by Manufacture	Value Added by Manufacture per Establishment (*Thousands of dollars*)	Horsepower	Horsepower per Establishment
1899..	350	17,519	50	25,629	8,717	34	73	.....[a]	...[a]
1905..	329	22,294	68	37,339	12,319	33	113	93,791	285
1909..	401	25,981	65	58,094	15,591	27	145	214,413	535
1914..	427	35,375	83	77,084	24,279	31	181	288,909	680
1919..	836	76,918	92	312,760	105,062	34	374	480,435	570
1921..	728	49,138	67	211,959	62,161	29	291	.....[a]	...[a]
1923..	773	77,254	100	326,678	103,301	32	423	592,023	770
1925..	751	57,890	77	287,598	83,537	29	383	546,797	730
1927..	492	52,347	106	275,414	78,275	28	560	576,285	1,170
1929..	551	62,199	113	374,472	94,680	25	680	854,358	1,550
1931..	558	48,522	87	287,107	66,360	23	515	.....[a]	...[a]

* Data up to 1929, United States Department of Commerce, Bureau of the Census *Fifteenth Census of the United States, Manufactures 1929*, reprint on "Chemicals, Compressed and Liquefied Gases" (Washington, D.C., 1932), p. 1. Data for 1931 from same source, release (Ind. No. 168) on "Chemicals Not Elsewhere Classified."

[a] No data.

than a fourth in 1931. A good index of the growth of large-scale production is the value added by manufacture per establishment. Notice that it has increased six- or sevenfold in dollar terms despite the fact that in 1931 the prices of chemicals as a whole, primarily because of the proliferation of new and cheaper processes and substitutes, were lower than in 1899 (notably true of sulfuric acid, as has already been

shown). This is an increase of from three to four times that in the number of laborers, and, as is shown by the diminishing share of the wage dollar in total value added by manufacture, is considerably greater than the increase in labor cost. It is an increase that, however, can be readily explained from the figures on power used per establishment which similarly rise sixfold. In short, it reflects the increasing use of automatically operating fixed plant, power driven, requiring a great deal of capital investment,[3] of large turnover, heavy obsolescence and depreciation charges, and of smaller outlays for labor—in sum, of large-scale capitalistic production.

REASONS FOR THE GROWTH OF LARGE-SCALE MANAGEMENT

The data so far considered apply only to the chemical "establishment," which in census terminology signifies a single plant or factory. While it may refer on occasion to "two or more plants operated under a common ownership and located in the same city, or in the same county but in different municipalities or unincorporated places having fewer than 10,000 inhabitants," these instances are counterbalanced somewhat by the occasions when "separate reports are obtained for different industries carried on in the same plant in which event a single plant is counted as two or more establishments." Consequently, the figures above give but little clue to the size of the unit of management, nor are such data to be had from the census reports.

Yet the growth of the size of concerns has been one of the

[3] The ratio of total capital to total value of products can be given only for the years 1904, 1909, 1914, and 1919 when capital was reported by the census. For those years it is 1.41, 1.89, 2.32 and 1.63, respectively, in the sulfuric, nitric, and mixed acids industry. In manufacturing industries generally the average amount of capital required per dollar value of product put out was only \$0.86, \$0.89, \$0.94, and \$0.71, respectively; that is, less than one-half as much capital outlay per dollar's worth of goods produced was required in manufacturing generally as in the sulfuric acid business.

most striking features of modern industrial chemical development. While precise statistical measurements are lacking, the few examples presently to be given will more than suffice to establish the spectacular nature of this trend toward corporate bigness. The reasons, while reducing fundamentally to the desire to minimize risk, are as diverse as the forces impinging upon a modern sulfuric acid and chemical business.

The theoretical range and nature of the possibilities in this connection are readily seen in the light of a few principles of chemical economics or "theoretische wirtschafts chemie."[4] It classifies these impinging forces into three groups—economic, chemical, and technical—and recognizes that all of them are interdependent and interact, all are highly dynamic, and if ever in balance at best for but a short time. Sudden shifts in demand, for example, cause shifts in the supply of items jointly produced, which in turn produce price changes or marketing pushes that affect a wide range of substitutes. Sudden shifts in the supply of a given item bring shifts in the demand for items jointly demanded, which in turn causes production readjustments and price changes both upward and downward, depending on the joint-cost relationship present.

Similarly, national policy with respect to prices, tariffs, patents, cartels, finance, labor, technical education, and research profoundly influences the chemical and technological state of the arts and the types of business organization that become the units of intercompany competition. But chemical research and technology gradually coalesce discontinuous

[4] This is the term given to this range of subjects, lying between the sciences of chemistry and economics, by R. Koetschau, *Einführung in die Theoretische Wirtschafts Chemie* (Theodor Steinkopf, Dresden und Leipzig, 1929). One of the earlier German treatises to attract international attention was that of A. Sulfrian, *Lehrbuch der chemisch-technischen Wirtschaftslehre* (Ferdinand Enke, Stuttgart, 1927). In this country the subject has not as yet been adequately treated, though Chaplin Tyler's *Chemical Engineering Economics* (McGraw-Hill, New York, 1926) does a good job from the point of view of the individual business but makes no attempt to treat the subject from the point of view of society or of economic principle.

processes into continuous ones, replace batch operations by complete unit operations—use, for example, the continuous filter or autoclave or molding machine—and thus reduce operating charges and increase productive capacity per unit of investment. Often, when both chemistry and economics, the process and the market, are ready, technology has not yet been able to make the equipment. The essential contribution, for example, of Dr. Bosch toward making Dr. Haber's laboratory synthetic-ammonia process a plant operation on a large scale was primarily technological, involving a study of resistances of materials to simultaneous action of high pressure, temperature, and corrosion. It is technology that must build new equipment for new processes, invent new devices for handling large quantities of boiling, freezing, viscous, effervescent, sticky, corrosive, and poisonous gases, liquids, and solids—all within a definite space of time, in definite volume, and in a specified chemical state.[5] Examples could be multiplied.

Suffice it to say that (1) economic forces (those characterizing the situation of a particular business, its methods of organization and management, and its striving for profits; those characterizing the industry and its peculiar conditions of supply and demand; and those characterizing an economy with its price and credit policy, its tariffs, and so forth), (2) chemical forces (those radiating from the scientific laboratories of chemistry, physics, physical chemistry and biology; those in industrial research laboratories developing new and more automatic methods of control, new ways of economizing on raw materials, labor and power, and new devices for improving yield), and (3) technological forces (those of chemical engineering, of mechanical engineering, of alloy pioneering, of thermodynamics—heat, pressure, and catal-

[5] For a theoretical development of the types of equilibrium between the economic, chemical, and technological forces at work, see R. Koetschau, *op. cit.*, especially pp. 86–97.

sis—and of electrical engineering)—these reciprocally stimulate and condition each other in such a myriad of interrelationships (each operating as a vector but of length and angle that often must be "guestimated") that the task of fully mirroring the details of intercompany competition is impossible except it be limited to simple and sweeping strokes of description covering a suggestive sample. No detailed enumeration or exhaustive analysis will be attempted.

ECONOMIES OF INTEGRATING PRODUCTION ACTIVITIES

The original and most important force impelling a company toward multiplication of products is, of course, the opportunity and competitive necessity to process wastes or by-products. Once the chain is begun there is frequently no good place to end until the company has gone around the circle of products. In Figure 13 is shown how one of our largest chemical companies branched out from the manufacture of explosives into a vast range of other chemicals, prominent among them sulfuric acid. In its report to the stockholders the company gives as the main reason: "The diversified chemical industries which constitute your company's business are basically closely related. This relationship consists of similarity or identity of raw materials and of processes of manufacture. . . . . Explosives have as their principal raw materials, nitric and sulphuric acids, ammonia, glycerin, alcohol, coal-tar intermediates, cotton and wood pulp."[6] Notice on the chart that coal-tar dyes, lithopone, dry colors and pigments, nitrocellulose lacquers such as Duco, pyroxylin ware, tetra ethyl lead, and rayon are all shown as consumers of sulfuric acid.

Other companies have started from the production of other chemicals and ultimately come to produce nearly as wide,

[6] E. I. du Pont de Nemours & Company, *Annual Report 1927* (Wilmington, Delaware, 1927), p. 8.

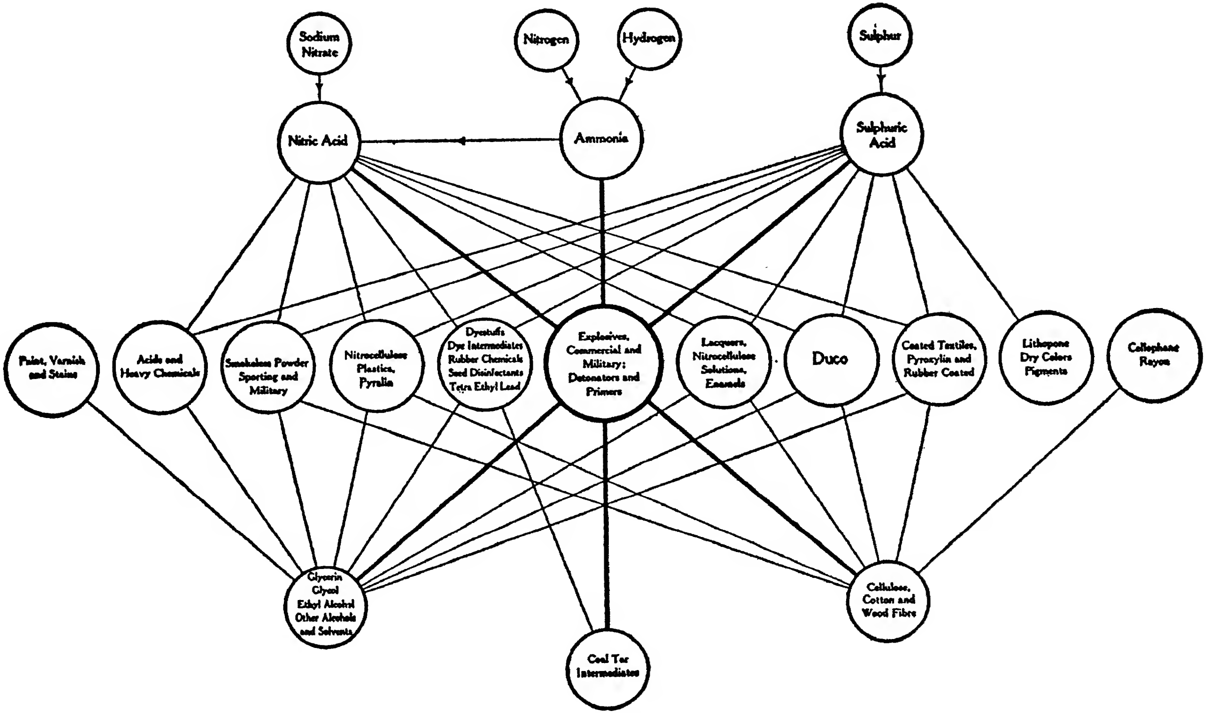


FIG. 13.—The kinship of du Pont products. From E. I. du Pont de Nemours & Company, *Annual Report 1927* (Wilmington, Delaware, 1927), p. 8.

though each a somewhat different, range of products. The Grasselli Chemical Company, in Cincinnati, Ohio, and the General Chemical Company began with the production of sulfuric acid, the Monsanto Chemical Company at St. Louis with saccharin and other synthetic organic products, and Merck and Company with medicinals. The Calco Chemical Company began operations by making wall coverings made from jute cloth manufactured in Scotland and colored with dyes imported from Germany, the Philadelphia Salt Manufacturing Company by making lye, the American Cyanamid Company by producing calcium cyanamid, and the Stauffer Chemical Company by making sal soda. Now each of these companies produces scores of products, of which some are individual specialties, some are produced by two concerns, others by three or four, and a few by all of them.

ECONOMIES OF INTEGRATING SALES ACTIVITIES

The reasons for expansion from product to product are not solely inherent in processes of production or in split-up of raw materials. They also derive from the interrelationship of the markets for sulfuric acid and kindred chemicals. Table 46, below, indicates that chemicals are for the most part consumed by a range of industries that lean heavily on chemical-engineering methods of production (a not unexpected result). But such close interconnection offers remarkable opportunity "for consolidations or operating arrangements between non-competing and complementary plants. The community of economic interest and the free interchange of raw materials, intermediates, and even finished products which is possible in such large industrial organizations eliminate much of the waste chargeable to distribution and sales competition."[7] By

[7] "A Concentrated Industrial Market for Heavy Chemicals," *Chemical and Metallurgical Engineering* (September 1927), Vol. XXXIV, No. 9, p. 586.

TABLE 46

MARKET INTERRELATIONSHIPS OF SULFURIC ACID, 1935*

Consuming Industries	Sulfuric Acid (*Short Tons 50° Bé.*)	Hydrochloric Acid (*Short Tons 100%*)	Nitric Acid (*Short Tons 100%*)	Acetic Acid (*Short Tons 100%*)	Oxalic Acid (*Short Tons*)	Alum $Al_2(SO_4)_3$ (*Short Tons*)	Sodium Sulfates (*Short Tons*)	Ammonia (*Net Tons Nitrogen*)	Sulfur (*Long Tons*)	Lime (*Short Tons*)	Gypsum (*Short Tons Calcined for Manufacturing*)
Heavy chemicals	723,000	20,000	10,000	10,000	200	15,000	10,000	102,000	570,000	300,000	2,000
Dyes and organic chemicals	210,000	22,500	30,000	41,500	300	500	10,000	4,500	65,000	17,000	....
Plastics and resins	8,500	....	....	3,500	...	....	....	100	....	25,000	....
Wood chemicals and naval stores	7,500	500	....	....	...	....	....	....	....	6,000	....
Glass and ceramics	500	1,500	....	....	...	250	41,000	....	....	686,000	61,000
Manufactured gas and coke	625,000	....	....	....	...	....	....	....	....	50,000	....
Explosives	175,000	....	100,000	....	...	....	....	25,000	42,000	7,000	....
Fertilizers and insecticides	1,730,000	....	500	....	...	...	....	127,000	239,000	100,000	....
Leather, glue, and gelatine	17,000	16,750	....	4,000	200	500	1,000	100	....	123,000	....
Oils, fats, and greases	14,000	1,000	....	....	...	200	....	....	....	....	....
Paints and pigments	400,000	....	2,500	2,500	...	750	....	....	4,000	....	1,000
Pulp and paper	1,500	....	....	....	...	17,500	225,000	....	204,000	344,500	2,000
Petroleum refining	1,000,000	....	....	....	...	....	....	4,000	7,000	100,000	....
Rayon and cellulose film	309,000	....	....	18,000	...	....	5,000	400	....	....	....
Rubber goods	22,500	....	....	....	...	....	....	200	33,000	5,000	....
Soap and glycerine	6,000	2,500	....	....	...	....	2,000	300	....	13,000	....
Sugar and food products	3,500	1,000	....	10,000	...	500	....	5,000	4,000	19,500	....
Textile processing	90,000	7,500	200	10,000	1,000	5,000	80,000	500	....	5,000	....
Total for process industries	5,343,000	73,250	143,200	99,500	1,700	140,200	374,000	269,100	1,168,000	1,801,000	70,600
Total for other industries	1,382,000	1,750	10,600	3,500	3,300	174,800	28,000	10,900	54,000	1,154,000	23,400
Total distribution	6,725,000	75,000	153,800	103,000	5,000	315,000	402,000	280,000	1,222,000	2,955,000	94,000

* Excerpt from a table of estimaates of *Chemical and Metallurgical Engineering* (February 1937), Vol. XLIV, No. 2, pp. 58–59.

virtue of this interrelationship of uses and users, research, technical experience, and the area of common trade knowledge concerning technical specifications, cautions in transport, handling, and consumption are made more generally valuable. Consequently every whit of contribution possible can be created by strength, purity, and performance of raw materials toward securing the maximum yield and hence the lowest manufacturing cost from given processes, plant, and equipment.

Finally, it should be noted that the advantage of such a common fund of chemical knowledge may lead to an extension of operations far beyond the production of chemicals. It not only may but often does lead to the development of subsidiary parts of plant or subsidiary corporations that specialize in making the precise kind of chemical equipment needed. Mention has already been made of the fact that one of the largest companies producing sulfuric acid, the American Cyanamid Company, has a subsidiary, the Chemical Construction Company, that specializes in putting up sulfuric acid plants. But operations may and do ramify far wider than that. As the General Chemical Company states:

> We may say that a well-equipped, well-integrated chemical enterprise of our day finds itself obliged to enter upon many other fields besides that of pure chemistry. It should enter the mining business to obtain its raw materials. It should know how so to treat crude ores as to adapt them for further uses. It should go into the transportation business in so far at least as to maintain tank cars and tank boats and motor trucks. It may need to establish potteries and foundries to secure advantageously the apparatus best adapted to chemical processes. It must be superior in engineering. It may need to enter the real estate field and to build and to rent houses; even to become a great caterer and furnish food for thousands. It will need to maintain hospitals and to learn how to care for the sick and injured; it must be something of a sociologist and study the conditions best adapted for labor efficiency: and in order to practise successfully all these technical arts that have become conditions of success in the

chemical industry, it must provide itself with a general staff of veritable experts in all these fields.[8]

Companies producing sulfuric acid thus tend to become nearly self-sufficient. The towns which grow up about the plants of the huge chemical concerns have many similarities with medieval feudal baronies, especially so abroad. (The significance of this fact for labor will occupy our attention in the next chapter.) Company towns, however, represent only conspicuous and exceptional instances. The usual type of self-sufficiency is that obtained by spreading operations over many states, having a system of distribution set up so as to be able to tap every important market, by acquiring plants producing the most necessary raw materials as advantageously as possible, and in general by making nearly everything it needs, including equipment (because often in the process of sufficiently describing and specifying the equipment needed to a third party, the details of a secret process representing the fruits of years of research have to be revealed before reaching maximum patentable development). Through such diversification risks are made a minimum.

STABILITY THROUGH ENTENTES AND MERGERS

One of the most popular methods of obtaining business stability is by consolidation of interests. As has been shown, chemical competition operating with weapons forged in commercial and chemical-research laboratories and evolving new processes, new uses, and new by-products in endless succession, has continually upset established techniques and channels of trade, has made cost figures arbitrary if not meaningless, and has perpetually threatened the equilibrium and stability of the market. Consequently, in every country in the

[8] *The General Chemical Company after Twenty Years, 1899–1919* (privately printed, 1920), p. 37.

world, no matter what its tariff or antitrust policy, the chemical industry has been characterized by the emergence of numerous cartels, conventions, pools, communities of interest, and mergers.

Long before the advent of NRA the alert sulfuric acid executive had seized upon devices of stabilization and rationalization. He kept labor turnover at a minimum and regularized employment. As has already been noted, he maintained the price of sulfuric acid at the same level for long periods of time, a phenomenon which almost necessarily implies a policy of "live and let live," of competing in service rendered but apportioning sales and indirectly allocating production. Patents and technical experience were pooled. Intercorporate stock ownership, interlocking directorates, cross-licensing arrangements, exclusive purchase and sales agreements—these are only a few of the devices whereby producers tried to make sure of raw material or other essential supplies and sought to give a degree of permanence and predictability to their market.

Intercompany competition is therefore not that of smoothly working automatic market equilibria that go on independently of what the individual company produces or sells, beyond his individual control or knowledgeable influence. Intercompany competition in the sulfuric acid business is frankly monopolistic competition, "competition at times the more severe and unprincipled because the competitors are giants and the devices manifold. Financial and commodity *haute politique,* fought with such weapons as . . . . patents and threat of producing [market invading] by-products, has proximately determined not only price but even demand and supply."[9] Even when there is stability of price, there remains a variety

[9] T. J. Kreps, chapter xi, "The Chemical Industries," in George Galloway (ed.), *Industrial Planning under Codes* (Harper and Brothers, New York and London, 1935), p. 228.

of competitive devices of considerable importance. The catalogue of prohibitions in some of the chemical codes affords instructive insight into the type of practices which chemical manufacturers sought to control. While too extensive to enumerate here, they include prohibitions against concealed allowances, against excessive rebates on containers, against unearned discounts, free distribution services, espionage by competitors, enticement of employees, unjustified claims adjustments, contingent sales, dumping, and, of course, sales below cost.

So universal is this striving in intercompany competition toward some type of stability that treatises on chemical economics sometimes frankly say:

> Monopoly is another quality of chemical markets. . . . . When manufacturers strive to increase consumption by reduction of price . . . . unfortunately others may get the idea simultaneously, and overproduction for a saturated market will result. Chemical industry due to the comparatively large size of its individual units, generally avoids these disastrous misunderstandings. The French word 'entente' is nicely expressive of customary agreements in price, production, and markets. . . . . That profit has been as large as it has been can be directly traced to the balancing effect of monopoly and price control common in the industry.[10]

Such monopoly efforts, while aided by local concentrations of raw material and by patents, are, however, hindered in several ways. Chemists find substitutes, natural or synthetic. New processes, new products, new types of equipment, and new competitors keep springing up to break cartels, whether of price, or production, or of sales, especially if they apply to only one item. Consequently, even the highly competitive German industry finally became substantially unified in a merger of former communities of interest called the

[10] L. M. Bernard, "Chemical Business from the Economic Point of View," translated from *Chimie et Industrie* by Joseph Kalish, *Chemical Industries* (October 1933), Vol. XXXIII, No. 4, p. 317.

Interessengemeinschaft Farbenindustrie Aktiengesellschaft (producing 90 per cent of Germany's mineral acids). A similar development in Italy has brought the preponderance of chemical production there under Montecatini Società Generale per l'Industria Mineraria et Agricola (producing 60 per cent of Italy's sulfuric acid). In France it has been centralized under the Compagnie Nationale de Matières Colorantes et Manufactures de Produits Chimiques du Nord Réunis Établissements Kuhlmann (producing 70 per cent of France's mineral acids), and in England under the Imperial Chemical Industries, Ltd. (producing 95 per cent of Britain's heavy chemicals).

THE GENERAL CHEMICAL COMPANY

The United States has been too large to permit a similar development here, i.e., one concern acquiring dominant control of the entire chemical industry. But there are concerns operating here that are larger than those in Europe. Among these, seven in particular are of such importance in the sulfuric acid trade as to warrant brief attention.

The first in point of time as far as the process of consolidation is concerned is the General Chemical Company, one of the units of the Allied Chemical and Dye Corporation. Incorporated in 1899, it consolidated under the leadership of Dr. William H. Nichols no less than twelve chemical companies, practically all of them producers of sulfuric acid.[11] Its capital

[11] Some of the firms which united were: The Chappell Chemical Company, Chicago, Illinois, and St. Louis, Missouri; The Dundee Chemical Works, Dundee, New Jersey; The Fairfield Chemical Works, Bridgeport, Connecticut; The Highlands Chemical Company, Highlands, New York; James Irwin and Company, Pittsburgh, Pennsylvania; The Lodi Chemical Company, Lodi, New Jersey; The Martin Kalbfleisch Chemical Company, Bayonne, New Jersey, and Buffalo, New York; James L. Morgan, Shadyside, New Jersey, and Bridgeport, Connecticut; The National Chemical Company, Cleveland, Ohio; The Nichols Chemical Company, Laurel Hill, Long Island, Troy, and Syracuse, New York, Capleton, Canada; The Moro Phillips Chemical Company, Philadelphia, Pennsylvania, and Camden, New Jersey.; The Passaic Chemical Company, Newark,

originally was $14,000,000. The reasons given for this horizontal combination were many. First of all, the plants individually "lacked the income for efficient research work on a large scale, so indispensable in the chemical field."[12] Second, there were the usual reasons for consolidation which used to occupy so large a place in economic textbooks, namely, the avoidance of cross freights, the pooling of technical experience, managerial skill, specialization of plant operations, utilization of wastes and by-products, utilization of advertising and salesmen for a larger line of goods, regulation of middlemen, control of terms of credit and sale, consolidation of financial resources, wider access to raw material markets, product standardization, and, especially, freedom from local risks and flexibility in making adjustments to shifts in supply and demand.

During the next twenty years the General Chemical Company began to acquire properties other than sulfuric acid plants. While it had in the beginning provided itself with a fleet of lighterage vessels through acquiring control of the General Lighterage Company, it began to expand its fleet of tank cars for transporting acid in bulk. This idea had been conceived more than twenty years earlier, in 1873, by the Nichols Chemical Company, which then shipped the first carload bulk shipment of sulfuric acid that traveled by rail "from the Nichols works in Long Island City, New York, to the Pittsburgh steel-mill district."[13] Now more than a thousand tank

New Jersey; The General Lighterage Company, 25 Broad Street, New York. This, together with other financial and business data, has been obtained from annual reports of the company as well as its statements to the Stock Exchange, from newspaper clippings, and from other items collected by the Library of the Harvard Business School. Other valuable materials utilized were found in the collection of the Business Historical Society in Boston.

[12] *The General Chemical Company after Twenty Years, 1899–1919* (privately printed, 1920), p. 14.

[13] "Chemical Industry's Contribution to the Nation, 1635–1935," *Chemical Industries* (Supplement, May 1935), p. 100.

cars are owned through the medium of the Crescent Tank Line. Soon after organization the General Chemical Company took over the Baker and Adamson line of reagent chemicals, which varied its product from mass manufacture to quality refinement. The Thomsen Chemical Company of Baltimore was absorbed in the original consolidation and with it the brand name and product good will it had built up in insecticides and fungicides. At Camden, New Jersey, the company established its own foundry and pottery, thereby being able to produce its own castings and earthenware vessels. It also owns pyrites properties near Capleton, Canada, and Pulaski, Virginia, in addition to which it operates a chain of sales offices, distributing stations, and warehouses.

In 1920 the General Chemical Company became the largest single factor in the well-known Allied Chemical and Dye Corporation, contributing 27 per cent of the total net worth of the consolidation. The other companies amalgamated together were: the Solvay Process Company, contributing 16 per cent; the National Aniline and Chemical Company, contributing 21 per cent; the Barrett Company, 19 per cent; and the Semet-Solvay Company, 17 per cent. The value of all the assets of the group in 1935 was reported in that year at almost exactly 400 million dollars,[14] a figure almost equal to that of the huge German concern, the Interessengemeinschaft Farbenindustrie Aktiengesellschaft, which reported total assets of Reichsmark 1,743,822,466.70[15] in 1930 (at exchange rates of roughly 4 to 1, about $436,000,000).

The advantages of this new combination were stated to be "greater diversification of output and correspondingly greater stability of business; closer adjustment of the production of

[14] Total assets reported as of December 31, 1935, were $400,098,273. Standard Statistics Company, *Standard Corporation Records* (June 30, 1936), Vol. XIV, No. 3077, Sec. 5, Bulletin A 55, p. 8.

[15] Das Spezial-Archiv der deutschen Wirtschaft, *Der I. G. Farben-Konzern 1931* (Hoppenstedt, Berlin 1931), p. 67.

basic and intermediate materials to the requirements for the manufacture of their derivatives; and greater financial strength. Current developments in the chemical industry and therefore intensive progressive research is an especially important feature of the chemical business.[16]

Yet in 1920 the General Chemical had 16 plants located throughout the United States and Canada and was producing more than one hundred chemicals, among them sulfuric, acetic, hydrochloric, hydrofluoric, chromic, and nitric acids; ammonia, soda and potash alums; ammonia, aqua ammonia, acetyl chloride, carbon tetrachloride and bisulfide, petroleum ether, and phosphorus pentachloride; epsom salts, Glauber's salt, and salt cake; iron, iron sulfide, and copperas; sodium compounds in various forms including bisulfate, fluoride, hyposulfite, phosphate, sulfates, and so forth; tin bichloride and tetrachloride, and lead acetate; arsenates of calcium and lead, arsenite of zinc, Paris green, and various sulfur mixtures.

The companies with which it united were similarly strong and diversified in production. The Solvay Process Company at Syracuse, New York, and Detroit, Michigan, makes from 35 to 45 per cent of the total soda ash produced in the United States, in addition to being the most important single manufacturer of other soda alkalis, notably caustic soda, ammonium bicarbonate, laundry, textile, and tanners' sodas, and tanners' alkalis. The Semet-Solvay Company controls the Semet-Solvay by-product coke-oven patents and in 1930 operated 744 ovens scattered in Alabama, Detroit, Buffalo, Ashland (Kentucky), and Ironton (Ohio). Its main products are coke, gas, and ammonium sulfate. Its by-product tar and light oils are disposed of to the fourth company entering into the amalgamation, the Barrett Company, which further refines them into

[16] From the statement of the Allied Chemical and Dye Corporation to the New York Stock Exchange.

such materials as benzene, creosote, naphtha, carbolic acid, pitch, and aniline, road and roofing materials such as Tarvia, disinfectants, perfumes, flavoring materials, flotation oils and reagents, pickling inhibitors, rubber softeners, benzol, naphthalene, cresol, xylenol, cresylic acid, pyridine, and coumarine. These it manufactures in over thirty plants in the United States and Canada.

The other company to be combined was the National Aniline and Chemical Company, the oldest dyestuff concern in the United States, now making nearly a third of the total domestic output of dyestuffs in the United States. It uses the coal-tar crudes and intermediates of the Barrett Company and produces hundreds of dyes, organic acids, and other coal-tar derivatives. It also produces wetting-out agents for the textile industry, solvents and plasticizers for the lacquer trade, accelerators and anti-oxidants for rubber manufacturers, and a variety of other chemicals for the synthetic resin, mining, paint, wood preserving, insecticide, germicide, explosives, and pharmaceutical industries. In 1928 a new subsidiary, the Atmospheric Nitrogen Corporation (transferred in 1936 to the Solvay Process Company), began to produce sodium nitrate in a plant at Hopewell, Virginia, with a capacity of 700,000 tons annually. Another subsidiary, the Aldyco Corporation, is believed to operate as a security-holding enterprise, which, if true, means that it was managing at the close of 1935 nearly 27 million dollars' worth of government bonds and 23 million dollars' worth of marketable securities, including 224,000 common shares of the United States Steel Corporation, 90,000 shares of Air Reduction, Inc., 54,500 common shares of Sloss-Sheffield Steel and Iron Company, and 43,502 6 per cent participating preferred shares of the Virginia-Carolina Chemical Corporation. These concerns are among its largest actual and potential customers.

A final word remains to be said. The Allied Chemical

and Dye Corporation has been the sphinx among chemical concerns, relatively little being reported of its affiliations with concerns in other countries. It is known that the European group, centered about the Solvay interests in Belgium, has maintained more than a fifth proprietorship interest, has kept up an active interchange of technical and commercial experience, and has been continuously represented on the Board of Directors. In 1926 and 1927 Lord Melchett of the Imperial Chemical Industries, Ltd., served on the Board. But details of the interrelationship have never been authentically revealed. The published financial statements show a similar secretiveness, no figures on sales receipts, operating costs, and operations of subsidiary units being made available. The firm does not even participate in trade-association activities. Research workers and engineers play a distinctly secondary role in its operations. Financial considerations, and especially the strategic opportunities in Wall Street, dominate its managerial policy.

E. I. DU PONT DE NEMOURS & COMPANY, INC.

By far the largest among the chemical concerns in the United States is E. I. du Pont de Nemours & Company, Inc. Its sales run at present well over 225 million dollars annually and its total assets as of June 30, 1937, were reported at nearly 750 million dollars.[17] On this basis it is 50 per cent larger than the Interessengemeinschaft Farbenindustrie Aktiengesellschaft. The number of employees, however, in 1935, including those of wholly owned subsidiaries, was 41,000, and inclusive of controlled companies, 46,000, a

[17] Standard Statistics Company, *Standard Corporation Records,* E. I. du Pont de Nemours & Company, Inc. (August 24, 1937), Vol. XV, No. 3355, Sec. 13, Bulletin D 22, p. 3. I am indebted to this source for a good share of the facts presented in these pages.

figure only 40 per cent of that of the Interessengemeinschaft Farbenindustrie Aktiengesellschaft in 1931 (113,000).[18]

Founded in 1802 by a notable French family which migrated here at the invitation of Thomas Jefferson, the company made explosives for more than a hundred years. During the World War it produced a substantial part of the powder and ammunition used by the Allies. It was then that with the purchase of the Harrison Brothers plant (see Figure 14) in Philadelphia it joined unto itself the oldest sulfuric acid producing unit in the United States. After the war it branched out rapidly into a variety of chemical enterprises mostly through buying up other chemical companies outright and gradually merging or partitioning their business among the several du Pont departments. Every year since 1915 has witnessed the purchase, absorption, organization, or dissolution of several corporations. With the acquisition of the Grasselli Chemical Company in 1928, which began to produce sulfuric acid in Cincinnati in 1839, it became one of the largest producers of sulfuric acid in the United States.

The place which sulfuric acid occupies is evident from a consideration of the eleven main chemical divisions into which du Pont's has divided its manufacturing and sales organizations. Segregation has been made on the basis of groups of allied products but does not extend to the purchasing, engineering, and accounting departments. In order of volume of business in 1935 (there has been a certain amount of reorganization of departments since that date) they were:

1. The fabrics and finishes department, making, among other things, "Duco" for automobile, furniture, and home, and coated fabrics such as "Fabrikoid" and "Leatherette"

[18] Das Spezial-Archiv der deutschen Wirtschaft, *op. cit.*, p. 64.

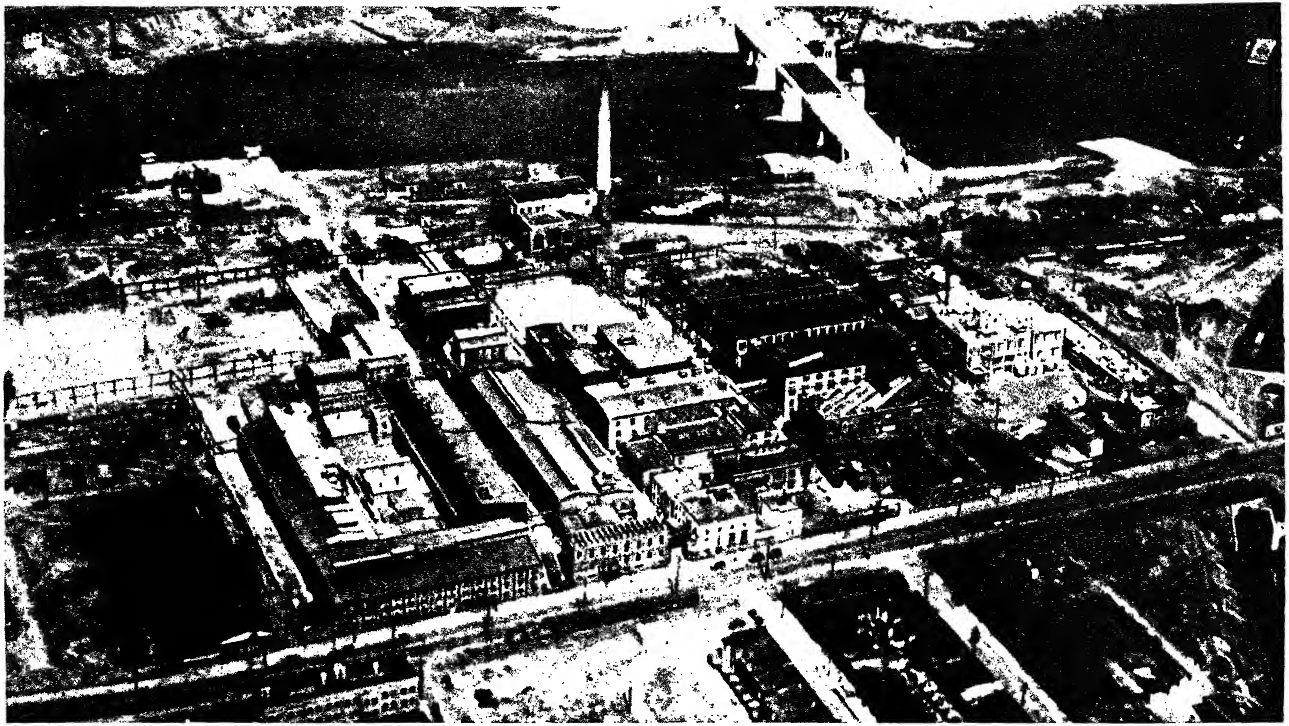


FIG. 14.—Where the manufacture of sulfuric acid started in the United States. The Harrison plant of the Du Pont Company at Gray's Ferry Road, Philadelphia (courtesy of *Chemical Industries*).

for upholstery, traveling equipment, bookbindings, and so forth.

2. The organic chemicals department, making dyestuffs, tetraethyl lead, "Duprene," refrigerants, and the like, at New Brunswick and Deepwater, New Jersey, and Carrollville, Wisconsin.

3. The du Pont Rayon Company, making rayon in plants at Buffalo, New York; Old Hickory, Tennessee; Richmond, Virginia; and Waynesboro, West Virginia.

4. The Grasselli Chemical Company, making inorganic heavy chemicals, with plants at Canton, Niles, Lockland, Toledo, and Cleveland, Ohio; at East Chicago, Fortville, and Terre Haute, Indiana; at Grasselli and Paulsboro, New Jersey; at New Castle and Philadelphia, Pennsylvania; at Meadowbrook and Weirton, West Virginia; at Detroit, Michigan; at Wurtland, Kentucky; at Baltimore, Maryland; and at Edge Moor, Delaware.

5. The explosives department, which even less than fifteen years ago did 40 per cent of the total business, producing commercial explosives and blasting accessories in 16 plants located in 11 states.

6. The du Pont Cellophane Company, Inc., a direct creation of its remarkable research laboratories.

7. The R.(oessler) & H.(asslacher) Chemicals department, producing electrochemicals and chemical specialties such as sodium peroxides, cyanides, solvents, rubber accelerators, fumigation chemicals, and reclaimed rubber.

8. The du Pont Viscoloid Company, producing such things as Lucite, Pyralin, and Arlton boudoir accessories, combs, rods, transparent sheeting, and phenolformaldehyde cast resins.

9. The Krebs pigment department, specializing in such items as lithopone and titanium dioxide.

10. The ammonia department, producing synthetic am-

monia, methanol, "Zerone" anti-freeze, aqua ammonia, and other ammonia products.

11. The smokeless powder department, which, though the smallest, none the less puts out under the Remington Arms Company, Inc., one-third of the domestic production of firearms and ammunition and in addition is the largest producer of pocket cutlery in the country.

The policy of du Pont's in contrast to that of the Allied Chemical and Dye Corporation has always been one of keeping the public fully informed through excellent quarterly and annual reports. Throughout its history it has been research-minded and has given chemists and engineers the top posts in its management. It has continually sought for new products, and has scored many signal triumphs, e.g., Duco and tetra-ethyl lead. It has extensive holdings and subsidiaries in foreign countries and owns about ten million shares, or nearly 23 per cent, of the common stock of General Motors. Therefore, "earnings are dependent in no small measure on the rate of activity among makers of automobiles, as most of them are large users of du Pont products. However, the company does business with so many other large industries, and products are so diversified, its manufacturing operations usually are well stabilized; moreover, the absence of destructive price competition for many products is an added advantage."[19]

AMERICAN CYANAMID COMPANY

One of the most recent to round out its line of chemical products is the American Cynamid Company (incorporated in 1907), which "now owns and operates, directly or indirectly, 28 American plants in 19 states and employs 6,500

[19] Standard Statistics Company, *Standard Corporation Records*, E. I. du Pont de Nemours & Company, Inc. (May 17, 1937), Vol. XV, No. 3230, Sec. 5, Bulletin D 21, p. 3.

American workers."[20] Its total assets are only about a tenth of du Pont's, being reported as $60,436,000 in 1935. It produces over 150 chemicals, but its main business until recently was making calcium cyanamid and "Ammo-Phos" fertilizer. At the present time it produces a wide variety of acids, explosives, industrial chemicals, flotation reagents, insecticides, esters, plasticizers, synthetic resins and plastics (Rezyl), tanning agents, case-hardening compounds, zinc and copper cyanides, pharmaceuticals such as chinchopin and tolysin, sutures used in surgery, antitoxins, vaccines, and so on.

Its place in the sulfuric acid business is a notable one. In the first place it absorbed the venerable Kalbfleisch Corporation, Heller and Merz, and the Calco Chemical Company, the last-named being one of the first to produce azo and basic dyes on a large scale during the World War and at present making nearly 500 items for all the color-consuming industries. Its plant at Bound Brook, New Jersey, has over 50 manufacturing buildings, warehouses, and laboratories, representing an expenditure of over $20,000,000, and employs over 2,000 people.[21] In the second place, one of its divisions, The Selden Company, controls a vanadium catalyst of great importance to the success of the contact process at the present time. Finally, its engineering division, the Chemical Construction Corporation, has to its credit a number of engineering developments of primary significance, notably the acid-proof masonry construction for sulfuric and nitric acid towers, the two-stage submerged-pipe type of sulfuric acid concentrator so useful in the acid-recovery systems of oil refineries, and a simplified ammonia oxidation unit.[22] It specializes in building contact and chamber plants.

[20] "Chemical Industry's Contribution to the Nation, 1635–1935," *Chemical Industries* (Supplement, May 1935), p. 127.

[21] *Ibid.*, p. 109. [22] *Ibid.*, p. 127.

THE MONSANTO CHEMICAL COMPANY AND OTHERS

Representative of the moderately large type of firm in the sulfuric acid business, the Monsanto Chemical Company began in 1901 as a producer of synthetic organic chemicals, and to this day phenol, aspirin, vanillin, caffeine, and saccharin are important contributors to its earnings. It now makes over 300 chemicals and reported total assets at the end of 1936 equal to $44,947,240.[23] It owns nine plants in the United States, the principal ones being at St. Louis, Missouri, and East St. Louis and Monsanto, Illinois. It began to produce sulfuric, nitric, and hydrochloric acids in 1918 when it acquired the Commercial Acid Company, its chief supplier of these heavy chemicals. In 1920 it secured an interest in two English concerns, producing such coal-tar products as phenol, cresols, creosote oil, pitch, naphthalene, and pyridine. Through these it now exports nearly one-sixth of annual sales. In 1929 it succeeded in gaining better entrance to the markets of the industrial East when it took over the Merrimac Chemical Company, the largest heavy chemical producer in Massachusetts and one which had been in business there since 1853. Thus today it has become one of the most important factors in the sulfuric acid trade.

Another important producer of sulfuric acid is the Tennessee Copper and Chemical Corporation (formerly the Tennessee Copper Company) whose early operations have already been described (see pp. 133–34). Its reported total assets equaled $18,722,000 at the end of 1934 and sales slightly over $7,000,000. Its main product is fertilizer (its specialty is "Loma" for lawns, and so forth), which it makes and sells through three subsidiaries, the Southern Agricultural Chemical Corporation, which it formed in 1919 to take care

[23] Standard Statistics Company, *Standard Corporation Records*, Monsanto Chemical Company (May 3, 1937), Vol. XV, No. 3263, Sec. 7, Bulletin M 13, p. 11.

of its by-product acid; the Calumet Fertilizer Corporation; and the United States Phosphoric Products Corporation. In 1935 it sold 364,900 tons of chemical products (mostly fertilizer and sulfuric acid), 8,964 tons of copper, 803 ounces of gold, and 51,892 ounces of silver and made 95,194 tons of iron sinter.[24] Other products are copper sulfate, slag, gypsum building blocks, and gypsum plaster. The plants of its sulfuric acid division, the Tennessee Copper Company, were reported in 1929 to have an annual capacity of 400,000 tons of 60° Bé. sulfuric acid. It ships its products in tank cars operated by a subsidiary, the Southern Agricultural Tank Line, directly to outside customers or to its own fertilizer plants in Alabama, Georgia, Florida, Ohio, and Indiana.

Throughout the South one of the names to conjure with in the fertilizer trade is the Virginia-Carolina Chemical Corporation. It operates 37 fertilizer plants there, 19 of which are completely equipped to manufacture sulfuric acid. Its total assets were reported at the end of 1935 as $30,276,000, and its products in addition to mixed fertilizers and superphosphates include such specialties as "Bloomaid" for use in gardens, "Fairway" for use on golf courses and lawns, phosphoric acid, ferro-phosphate, and insecticides, especially the nicotine compound known as "Black Leaf Forty." Its financial history since the World War has paralleled the fortunes of the Southern cotton belt.

Of singular historical importance is the Davison Chemical Company of Baltimore, Maryland, established by the Davison family in 1832, owning 54 fertilizer plants mostly situated in the region adjacent to Curtis Bay, Maryland. Prior to 1914 it was solely a producer of sulfuric acid, its

[24] Standard Statistics Company, *Standard Corporation Records,* Annual Report and Statistical Section, Tennessee Corporation (August 10, 1937), Vol. XV, No. 3339, Sec. 5, Bulletin T 13, p. 9.

plant being equipped to put out 350,000 tons annually. Since then it has added to its works at Curtis Bay facilities for producing 400,000 tons of acid phosphate, 40,000 tons of other heavy chemicals, a copper-leaching plant, a sintering plant, and a contact acid plant in which silica gel mass is the catalytic agent. It owns nearly 4,000 acres of sulfur-bearing ore lands in Cuba, but these are not operated at present because of its favorable contact closed in 1927 with the European Pyrites Company, Ltd., whereby it buys pyrites from the Rio Tinto Company, Ltd. Its total assets were reported at the end of 1932 as $35,486,000. It is one of the largest producers of sulfuric acid in the industry and puts out in addition to fertilizers such products as magnesium fluosilicate, sulfate of aluminum, fluorides, insecticides, copper, iron sinter, castor oil, and cottonseed oil.

SUMMARY OF INTERCOMPANY COMPETITION

These brief descriptions of the operations of the most important producers of sulfuric acid indicate clearly the diversity of conditions of competition. In all cases sulfuric acid is but one of several, even hundreds, of products. In no case do two companies put out exactly the same list of products, nor are their main products an identical group except for the fertilizer concerns. Each of the concerns has a group of specialties the production of which constitutes their main activity. In the case of the Allied Chemical and Dye Corporation these specialties are soda products and coal-tar products. Du Pont's gain their main revenue from fabrics and finishes such as Duco, explosives, and rayon; and its subsidiary, the Grasselli Company, gets sulfuric acid in several of its plants as a by-product of zinc blende roasting operations. The American Cyanamid Company specializes in cyanamid products, the Monsanto firm in synthetic organic products such as saccharin and vanillin, and the other

corporations in phosphate fertilizers. None of them do business under the same conditions, and as far as sulfuric acid is concerned none of them in any given market ordinarily depart from the price more or less tacitly agreed upon and maintained.

The competition between the major sulfuric acid concerns in some of the more important states is shown in Table 47, below. In New Jersey, Pennsylvania, and Ohio

TABLE 47

SULFURIC ACID PLANTS BY COMPANIES, BY STATES, IN 1929*

State	General Chemical	Grasselli (du Pont's) Chemical	Monsanto Chemical	Calco Chemical (Cyanamid)	American Agricultural Chemical	Virginia-Carolina Chemical	Stauffer Chemical
Alabama ..							
California							
Colorado .							
Delaware ..							
Florida ...							
Georgia ..							
Illinois ...							
Indiana ..							
Kentucky							
Louisiana							
Maryland							
Massachusetts							
Michigan							
New Jersey							
New York							
North Carolina .							
Ohio							
Pennsylvania ...							
South Carolina							
Virginia							
Washington .							
Wisconsin ..							

* See Table 37, pp. 159–66.

practically all of the major companies operate sulfuric acid plants, but not elsewhere. While there is no precise appor-

tionment of territory, the fact appears clearly that the Virginia-Carolina Chemical Company operates mostly in the southeastern portion of the United States, the Stauffer Chemical Company in Texas and the Far West, the Monsanto Chemical Company in the Mississippi area from Minnesota to Arkansas, Grasselli in Ohio, and the General Chemical Company in New York and New Jersey. There is considerable overlapping, of course, and competition in every area with smaller concerns. Moreover, there are many products using sulfuric acid in the making which are sold on a national scale. In short, secondary competition is nationwide, but primary competition in the acid itself is regional.

The extent to which the important sulfuric acid producers compete in other groups of products and struggle for the same industrial markets is indicated in Table 48. The products listed are in every case those produced in substantial amounts by the company or division producing the sulfuric acid. Thus no production is listed to the right of the heading, "Coal-tar Products," under the General Chemical Company, because though it makes no small number of organic acids, the production of coal-tar crudes and intermediates, as we have seen, is concentrated in the Barrett Company and that of the finished coal-tar products in the National Aniline and Chemical Company. The columns of crosses, therefore, underrepresent considerably the competition of the parent concerns but do give a rough comparison of the competition between the divisions or subsidiary companies producing sulfuric acid. The first group of three companies compete all along the line, both in products and in markets. The second group of three, vigorous but relatively small concerns, produce acids and sodium compounds and compete in marketing their products in the textile, chemicals, paint-and-varnish, food, and petroleum industries; but the front line of competition is shorter. Notice, however, that the Monsanto Chem-

TABLE 48

PRODUCTS AND MARKETS OF SULFURIC ACID PRODUCERS IN 1930*

Item	Allied Chemical and Dye (General Chemical Only)	du Pont's (Including Grasselli Division)	American Cyanamid (Including Calco Division)	Monsanto (Including Merrimac)	Pennsylvania Salt Manufacturing Co.	Stauffer Chemical	New Jersey Zinc Co.	Tennessee Copper and Chemical Corporation	American Agricultural Chemical	Virginia-Carolina Chemical	Davison Chemical
Principal Products											
Acids	X	X	X	X	X	X	X	X	X	X	X
Nitrogen compounds	X	..	X	..	..	..	..	..	..	..	..
Sodium compounds	X	X	X	X	X	X	..	..	X	..	..
Potassium compounds	..	X	X	..	..	..	..	..	..	..	..
Alum and aluminum compounds	X	X	..	X	X	..	..	..	..	..	..
Bleaching compounds	..	..	..	..	X	..	..	..	..	..	..
Coal-tar products	..	X	X	X	..	..	..	..	..	..	..
Plastics and pyroxylin	..	X	X	X	..	..	..	..	..	..	..
Compressed gases	..	..	..	..	X	..	..	..	..	..	..
Pigments, paint, and varnish	..	X	..	X	..	..	X	..	..	..	..
Pharmaceuticals	..	..	X	..	..	..	..	..	..	..	..
Solvents	..	..	X	X	..	X	..	..	..	..	..
Miscellaneous chemicals	X	X	X	X	X	X	X	X	..	X	X
Principal Markets											
Textiles	X	X	X	X	X	X	X	X	..	..	..
Chemicals	X	X	X	X	X	X	X	X	X	X	X
Paint, varnish, lacquer	X	X	X	X	X	X	X	..	..	..	..
Food	X	X	..	X	X	X	..	..	..	..	X
Fertilizer	..	..	X	X	..	..	..	X	X	X	X
Insecticides, etc.	X	X	X	..	X	X	..	..	X	X	..
Pharmaceuticals	X	..	X	X	X	..	X	..	..	..	..
Cosmetics	..	..	..	X	..	..	X	..	..	..	..
Photography	..	X	..	X	..	..	..	..	..	..	..
Mining and metallurgy	..	X	X	X	..	..	X	..	..	..	..
Glass and ceramics	X	..	..	X	X	..	..	..	..	..	..
Leather	X	X	X	X	X	..	..	..	..	..	..
Rubber	X	X	X	X	X	..	X	X	..	..	..
Explosives	..	X	..	..	..	..	..	..	..	..	..
Pulp and paper	X	X	X	X	X	..	..	..	..	..	..
Petroleum	X	X	..	X	X	X	..	X	..	..	X
Building	..	..	X	..	..	..	..	..	..	..	X

* Excerpt from a table given by *Chemical and Metallurgical Engineering* (January 1930), Vol. XXXVII, No. 1, pp. 16–17.

ical Company is definitely in a stage of transition from a relatively small concern to one of large dimensions. The third major column shows the competition offered by zinc producers, who it will be remembered produced 16 per cent of the total sulfuric acid made in the United States in 1930.[25] The fourth group shows the limited range of items in which the Tennessee Copper and Chemical Corporation competes and is to be compared with the other three concerns, which are also primarily producers of fertilizers.

Between concerns such as these, competition, while keen in certain items, is nevertheless primarily one of service. Needless to say, the companies grouped together experience more competition with each other than with those in other groups. Even when they have sulfuric acid plants in the same state, however, competition may not be active simply because many states are sufficiently large to make shipping costs considerable even within the state. Each firm, moreover, has individual, frequently patented, specialties, from which a goodly share of its profits are derived.

A list of the principal products of two of the most vigorous

[25] The list of zinc producers getting sulfuric acid as a by-product from zinc blende roasting operations in 1931 and the location of the smelter was as follows (those preceded by a capital "A" had acid works at the smelter):

A The American Steel and Wire Co., Donora, Pennsylvania
A The American Zinc and Chemical Co., Langeloth, Pennsylvania
A The American Zinc Co. of Illinois, East St. Louis and Hillsboro, Illinois
The American Zinc Oxide Co., Columbus, Ohio
The Eagle-Picher Lead Co., Hillsboro, Illinois
A The Grasselli Chemical Co., Grasselli, Indiana; Cleveland, Lockland, Niles and Canton, Ohio; New Castle, Pennsylvania
A The Hegeler Zinc Co., Danville, Illinois
A The Illinois Zinc Co., Peru, Illinois
A The Matthiessen and Hegeler Zinc Co., La Salle, Illinois
A The Mineral Point Zinc Co., Depue, Illinois
A The Monsanto Chemical Co., East St. Louis, Illinois
A The National Zinc Co., Bartlesville, Oklahoma
The National Zinc Separating Co., Platteville, Wisconsin
A The New Jersey Zinc Co. (of Pennsylvania), Palmerton, Pennsylvania
A The United Zinc Smelting Corporation, Moundsville, West Virginia

sulfuric acid concerns is given below. Products in which they compete directly with each other are set in italics.

The 1937 Monsanto List for Industry	The Grasselli Alphabet of Chemicals
Accelerators	
	Acetate of Lead
Acetic Acid	*Acetic Acid* (commercial, glacial, pure, redistilled)
Alcohol	
	Alum
Aluminum Chloride	*Aluminum Chloride* (crystals, solution)
Aluminum Oxide abrasive grain	
Aluminum Sulphate	*Aluminum Sulphate* (commercial and iron free)
Ammonia Alum	*Ammonia Alum*
Ammonia Anhydrous	
Aqua Ammonia	*Aqua Ammonia*
Ammonium Benzoate	
Ammonium Hydroxide	*Ammonium Hydroxide*, C.P.
	Ammonium Nitrate
	Ammonium Sulphate, 99.5%
Ammonium Phosphates	
Amyl Acetate	
Anti-oxidants	
	Aqua Fortis
Aroclors	
	Arsenic Acid
	Barium Carbonate
	Barium Chloride
	Barium Sulphate (Blanc Fixe)
Battery Acid	*Battery Acid*
	Battery Coppers
	Battery Zinc
Belt Cement	
Benzene Sulfonic Acid	
Benzoic Technical Acid	
Benzotrichloride	
Benzoyl Chloride	
Benzyl Chloride	
	Bichromate of Soda
	Bichromate of Potash
	Bisulphate of Soda
	Bisulphite of Soda Solution
Bone Ash	
	Bright Zinc

The 1937 Monsanto List for Industry	The Grasselli Alphabet of Chemicals
Bronzing Liquids	
Butyl Acetate	
	Cadalyte[a]
	Cadalyte Bright Dip
	Cadmium
	Cadmium Anodes
	Cadmium Hydrate
	Cadmium Plating Equipment
	Cadmium Sulphide
Calcium Phosphates	*Calcium Phosphates* (dibasic, tribasic)
Calcium Pyro Phosphate	
Carbolic Acid	
Caustic Soda	
Cements	
Chlor Phenols	
Chlorine, Liquid	
Chlorsulfonic	
C.P.	
Chrome Sulfate	
	Chromic Acid
Cotton Solutions	
Cresols	
Cresylic Acid	
Cycline Oil	
	Delimer K[a]
Depilatory	
Detergents	
Diacetone Alcohol	
Dibutyl Phthalate	
Dichloraniline 1:2:5	
Dichlorphenol	
Diethyl Phthalate	
Dimethyl Phthalate	
Dinitraniline	
Dinitrochlorbenzene 1:2:4	
Diphenyl	
Diphenylphthalate	
Dopes (Lacquers)	
Dry Ice	
	Duclean—Iron drum cleaner
	2 Ethyl Hexenal
Ferrisul (Ferric Sulfate)	
Ferro Phosphorus	

[a] Trade-mark registered.

The 1937 Monsanto List for Industry	The Grasselli Alphabet of Chemicals
Fixalt	
	Fire Retardants
	Fixtan A & B
	Formic Acid
	G.B.S. Soda
Glauber's Salt	*Glauber's Salt,* Anhydro
	Glauber's Salt, Anhydrous
H Acid	
	Hydrochloric Acid
Hypochlorite of Soda	
	Hyposulphite of Soda Crystals
	Hyposulphite of Soda Granulated
	Hyposulphite of Soda Pea Crystals
	Indium (metal or oxide)
Inhibitors	*Inhibitor No. 3*—Non-Foaming
	Inhibitor No. 8—Foaming
	Insecticides and Fungicides
Lacquers	
	Lactic Acid, Edible, U.S.P.
Lampblack	
Maleic Acid	
Maleic Anhydride	
	Manganese Nitrate
Mertanol (Syntan)	
Mertec (acid and alkali resistant paint)	
Metachloraniline	
Metanitrochlorbenzene	
Methyl Salicylate	
Mixed Acid	*Mixed Acid*
Mold Paste	
Monochlorbenzene	
Monsanto Salt	
	Mossy Zinc
	Muriate of Tin Crystals
	Muriate of Tin Solution
Muriatic Acid	*Muriatic Acid*
Nitric Acid	*Nitric Acid,* commercial, engraver's grade, fuming
Nitrate of Iron	
Niter Cake	
Nitrobenzene	
Nitro-Cellulose Solutions	
	Nogas
Oil of Vitriol	
	Oleum

The 1937 Monsanto List for Industry	The Grasselli Alphabet of Chemicals
Ortho Amino Diphenyl	
Orthoanisidine	
Orthochloraniline	
Orthochlorphenol	
Orthodichlorbenzene	
Orthonitraniline	
Orthonitrochlorbenzene	
Orthophenetidin	
	Oxalic Acid
Para Amino Diphenyl	
Parachloraniline	
Parachlorphenol	
Paradichlorbenzene	
Paranisidine	
Paranitrochlorbenzene	
Paranitrophenol	
Paraphenetidin	
Paratoluenesulfonamid	
Paratoluenesulfonchloride	
Penetrants	
Perchloride of Iron	
Phenol	
Phosphates	*Phosphate of Soda,* Anhydrous, Mono
Phosphoric Acid	
Phosphorous Oxychloride	
Phosphorous Trichloride	
Phthalic Anhydride	
Plasticizers	
	Potassium Silicate Glass
	Potassium Silicate Solution
Pyridine	
Resins	
	Sal Ammoniac
Salicylic Acid	
Salt Cake	*Salt Cake*
Santolites (Resins)	
Santosite (Sodium Sulfite)	
	Sherardizing Zinc
	Silicate of Soda, Granulated, Anhydrous, G.4.S., Lump, Meta, Pulverized, "R-B," Solid Glass, Solution
	Snoflake Soldering Salts
Sodium Acetate	

The 1937 Monsanto List for Industry	The Grasselli Alphabet of Chemicals
Sodium Aluminate	
Sodium Bisulfite	
	Sodium Formate
	Sodium—Lead Alloy
	Sodium—Zinc Alloy
Sodium Phosphates	Sodium Pyrophosphate
	Sodium Silico Fluoride
Sodium Sulfide	
	Soldering Flux, Crystals, Solution
	Slab Zinc
Solvents	
Spreading Agents	
	Strontium Carbonate
	Strontium Nitrate
Sulfur	
Sulfuric Acid	*Sulfuric Acid*
Sulfuryl Chloride	
	Sulphate of Soda, Anhydrous, Technical
	Sulphate of Zinc
	Sulphide of Soda, Concentrated, Crystals, Flake, Fused Solid, Crystal
	Super Sulphate of Soda
Tanning Chemicals	
	Thallium Sulphate
Thinners	
	Titanyl Sulphate
	Tin Crystals
	Tinning Flux
Tricresyl Phosphate	
Tryphenyl Phosphate	
	Tri-Sodium Phosphate
Water Treating Chemicals	
Wetting Out Agents	
Zanthates	
	Zinc Anodes
	Zinc Chloride, Fused, Granulated, Solution
	Zinc Dust—Non Gassing
	Zinc Intermediate
	Zinc Oxide
	Tomahawk[a] 35% Leaded
	Snow Cap[a] 5% Leaded

[a] Trade-mark registered.

In the measure a concern has many such specialties, in that measure it is likely to flourish. Except, therefore, for such a company as the Allied Chemical and Dye Corporation with its substantial hold on the old line alkali and coal-tar trade, concerns depend for growth and development on new markets, new processes, new products. In short, as a general rule success in intercompany competition can be expressed in just one word: research.

XI. The Competitive Importance of Labor

Any attempt to assess the importance in interregional competition of differences in the price or quality of labor is at once seriously handicapped by the fact that there are so few quantitative data available. It is known that in the chemical industry generally the wage bill constitutes about a fourth of the value added by manufacture (see Table 45, p. 190). But so far as sulfuric acid itself is concerned there exist facts only for that portion of it formerly called the "sulphuric, nitric, and mixed acids industry." These, moreover, are available only for the period 1899 to 1927, and have the considerable weakness that they apply to a changing population of acid plants. Obviously a precise presentation is impossible.

So far as most of the labor requirements and conditions of production are concerned, however, it would seem plausible that they do not vary fundamentally wherever similar types of plant, equipment, and process are used. It may be that in the fertilizer industry, at least that part of it which operates small chamber plants in the South (that is, excluding such establishments as the Tennessee Corporation and the Davison Chemical Company), the labor force may be paid a lower hourly wage, may consist to a larger extent of colored workers, and may work longer hours. Similarly it would seem likely that in the petroleum, zinc-smelting, and copper-smelting industries the labor conditions in the sulfuric acid plants resemble strongly the regional conditions in the refineries, smelters, or roaster plants. These conditions of wages, hours, and employment are known to vary considerably as between the North and the South and between urban areas and rural areas, so that any general average of wages, hours, and so on, over the country as a whole

is likely to conceal important regional differences without revealing anything of instructive typical value.

QUANTITATIVE IMPORTANCE OF LABOR COSTS

Nonetheless, the data, such as they are, are presented in Figure 15, below. The top curve, that representing the phys-

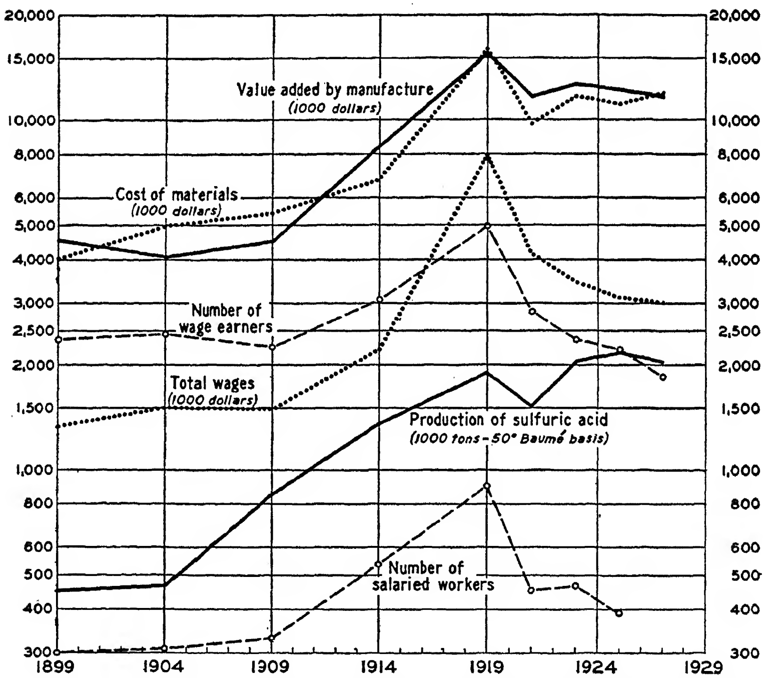


FIG. 15.—The place of labor in sulfuric acid manufacture, 1899–1929. For sources of data, see Table 49.

ical quantity of sulfuric acid produced by the "sulphuric, nitric, and mixed acids industry," after rising but slightly between 1899 and 1904, shows a very rapid growth in the next fifteen-year period, quadrupling to a figure of nearly 1,900,000 tons. After a decline in 1921 it rises to a new high in 1925. But not so the curves showing number of

salaried workers and number of laborers. They only double between 1904 and 1919 and thereafter decline rapidly and practically continuously, the number of laborers required being less in absolute numbers in 1927 than in 1899 when physical production was only a fifth as much.

The second group of lines, the lighter ones, representing measurements in terms of dollars, while in general corroborating the facts shown by the group of heavier lines, show variation in detail. All of the dollar figures run about the same until 1909, when value added by manufacture mounts very rapidly, cost of materials mounts less, and wages mount *much* less. All the curves come to a peak in 1919 and decline in 1921; but in 1923 wages paid continue to fall whereas the others rise to values of $12,709,000 for value added by manufacture and $11,695,000 for cost of materials.

The progressively increasing use of skilled technicians rather than unskilled wage earners is also shown in a fragmentary way on the chart. Between 1899 and 1925 there occurred a 30 per cent increase in the number of salaried persons, while the number of wage earners declined about 10 per cent. This may be due to some extent to a change in the wage contract from a daily, weekly, or biweekly basis to a salary schedule. For the most part, however, a real displacement of unskilled labor by skilled technicians took place, due to the increase in contact acid production, which, as was noted above, requires a higher order of engineering and chemical ability. The considerable increase in the number of salaried persons during the war period is undoubtedly closely connected with the flurry of contact acid production at that time. The subsequent decline, however, cannot be ascribed to a diminution in contact acid production but shows the influence of the growth of large-scale production and the increased automatization of both the contact and chamber processes. Instead of employing carefully trained

TABLE 49

Growth of "Sulphuric, Nitric, and Mixed Acids" Industry, 1899–1925*

			1909	1914	1919	1921	1923	1925	1927
Number of establishments	34		42	32			37		35
Wage earners, average number	2,356	2,447	2,252	3,064	4,961		2,357	2,196	1,837
Average number per establishment		76	54	96	127	79	65	61	52
Number of salaried workers				540		452			
Production of sulfuric acid (50° Bé. basis, thousands of tons)	453	468		1,359[a]		1,523	2,049	2,165	2,036
Average production per establishment (actual number of tons, 50° Bé. acid)	13,300	14,600	20,400	42,500	48,700	42,300	55,400	60,100	58,200
Average production									
Per salaried person	1,520	1,520	2,600	2,500	2,110	3,370	4,380	5,560	
Per wage earner	190	190	380	440	380	540	870	985	
Value of products in thousands	8,596	9,053	9,884	15,215	31,470	21,463	24,405	23,307	23,555
Cost of materials (thousands)	4,033	4,972		6,734	15,857	9,770	11,695	11,066	11,882
Value added by manufacture	4,563	4,080		8,481	15,613	11,693	12,709	12,241	11,672
Wages (in thousands of dollars)	1,327	1,505	1,495	2,212	7,916	4,137	3,456	3,103	3,014
Wages as a percentage of value added by manufacture		37		26	51	35	27	25	26
Horsepower		5,496	6,494	21,002	30,637		29,131	22,120	33,875
Horsepower per establishment		172	155	656	785		787	615	967
Value added per establishment (thousands of dollars)	134,200	127,500	107,100	265,000	400,300	324,800	343,500	340,000	333,500

* Reports of Bureau of the Census on "Sulphuric, Nitric and Mixed Acids Industry," in censuses of manufactures for the respective years.

[a] Amount for sale probably 90 per cent of production.

[b] No data.

observers, electric recording devices, for example, are used, which can be attended to by clerks, requiring only one expert as supervisor.

Substantiation of this contention is afforded by a comparison of the second group of figures (proceeding from top to bottom) in Table 49, especially by the quantities of sulfuric acid produced per salaried person and per wage earner. Notice that the increases between 1899 and 1925 are roughly 370 per cent and 520 per cent, respectively. Note also that the product per worker in 1919 was below that of 1914, though the product per establishment was higher; while in 1923 the apparent efficiency of the worker had more than doubled that of 1914. Product per worker varies cyclically, of course, with the extent of capacity operation, and so forth. Yet in the postwar period the product per worker continued at the level set in 1923. This would seem to indicate that in the 'twenties the chemist achieved an automatization and continuity of process which ultimately enabled the producer to dispense with laborers' services.

When attention is fastened on the third set of figures, those comparing wages with value of products, cost of materials, and value added by manufacture, the matter of automatization receives additional emphasis. The cost of raw materials, for example, is usually equal to and sometimes exceeds the value added by manufacture (see Figure 15). With cost of materials so important an item, obviously yields become of great significance in costs, the prime desideratum in labor being faithful, patient, and accurate attention to details—for example, keeping temperatures at the optimum so as to promote a maximum ultilization of raw materials, a minimum consumption of niter or of power, and so on. Moreover, a careful watch must be kept on corrosion in order to prevent expensive leaks and accidents.

A second fact appearing clearly from the table is that with

value added by manufacture roughly equal to only 50 per cent of the value of the product (cost of materials naturally constituting the other 50 per cent), and with wages constituting in recent years about 25 per cent of the value added by manufacture, the quantitative importance of wages in total costs reduces to an item of 12 to 15 per cent[1] and differences or variations in wages on the order of 20 to 30 per cent mean differences or variations in total cost of only $2\frac{1}{2}$ to $4\frac{1}{2}$ per cent. Actually to raise wages 50 per cent would increase the total cost somewhat less than 6 to $7\frac{1}{2}$ per cent, because the real cost of labor depends not only on the rate per hour but also on the ratio of labor to investment in plant and equipment and on the efficiency of the whole process in terms of quantity and quality of product. Employers find devices of apparatus and of management that economize labor, so that the net result is a more moderate increase in cost. This is not the only result, of course, for, obviously, even if one changes only the one factor—labor—one disturbs to different degrees in several industries not only the total costs of one product but the delicate balance of values received from other products which in their ensemble determine competitive policies and intercompany relationships. It is change that awakens resistance—for labor costs quantitatively are not a big item in total costs of making sulfuric acid.

IMPORTANCE OF CAPITAL COSTS

The item that is important, of course, is the cost of capital—interest, repairs, depreciation, and obsolescence. The value added by manufacture per laborer is consequently very high, generally nearly twice that in manufacturing enterprise as a whole. In 1923, for example, the value added in

[1] See, for example, the detailed cost of production figures given in Table 8, p. 68, and Table 11, p. 72, above.

the manufacture of sulfuric acid was roughly $4,500 per laborer, while the average for all manufacturing was only about $2,500 per laborer. This contrast gains importance when the fact is remembered that the price of sulfuric acid on the whole was below 1913 levels, whereas the index of general wholesale prices was about 60 per cent higher.

Another indicator of the utilization of capitalistic methods of production is given by the fourth set of figures in Table 49. The horsepower used per establishment increased more than sixfold between 1909 and 1927. The reverse side of this figure is, of course, the fourfold increase in the product per laborer between 1904 and 1929 and the more than fourfold increase in the average physical product per establishment in that period. Moreover, the value added per establishment, despite the fact that the average value of the product in 1927 was only about 60 per cent of the figure in 1899 ($11.50 versus $18.90), increased two and a half times from an average of $134,200 in 1899 to $343,500 in 1923, the latter figure for all manufacturing enterprise in 1923 being only $133,000. Thus although when compared with the steel or the automobile industry the scale of production in the sulfuric, nitric, and mixed acids industry is relatively small, actually it is nearly three times the average of manufacturing generally and seems to be still on the increase.

VARIATION IN LABOR REQUIREMENTS

The discussion so far has run entirely in terms of averages of a fluctuating number of plants. No information exists concerning the number of identical concerns or of "in-and-outers" in the census enumerations. Nor is a further breakdown possible except for particular years and then in terms of groups differentiated by value of product or by number of laborers employed.

In 1904, for example, of the 32 establishments in the sulfuric, nitric, and mixed acids industry one manufactured products worth $5,000 but less than $20,000, 10 made products in value over $20,000 but less than $100,000. The 21 establishments making between $100,000 and $1,000,000's worth of product produced 92.7 per cent of the total. In 1909 the census reported 19 establishments manufacturing products valued between $100,000 and $1,000,000 and 2 establishments making products that aggregated over a million dollars each in value, these 21 out of a total of 42 establishments making 87.5 per cent of the total for the industry. Correspondingly there were two establishments which employed nearly a fourth of the laborers, and seven employed more than one-half. Table 50 shows the details.

TABLE 50

Size of Establishment in the Sulfuric Acid Industry in 1909*

Wage Earners per Establishment	Number of Establishments	Number of Wage Earners	Percentage of Total
1- 20	18	211	9.4
21- 50	10	328	14.6
51-100	7	540	24.0
101-250	5	651	28.9
Over 250	2	522	23.2

* Department of Commerce and Labor, Bureau of the Census, *Thirteenth Census of the United States*, (Washington, D.C., 1913), Vol. X (*Manufactures*), p. 611.

But one more fragment of evidence requires attention. It consists of the results of a survey of the "chemical" industry made by the National Industrial Conference Board in November 1934, and shows that 10.2 per cent of the plants then employed 61.3 per cent and 1.2 per cent employed 17.7 per cent of the total employees in the industry. Thirty plants employing over 501 persons gave work to 26,305 employees, while the other 548 plants gave work to only

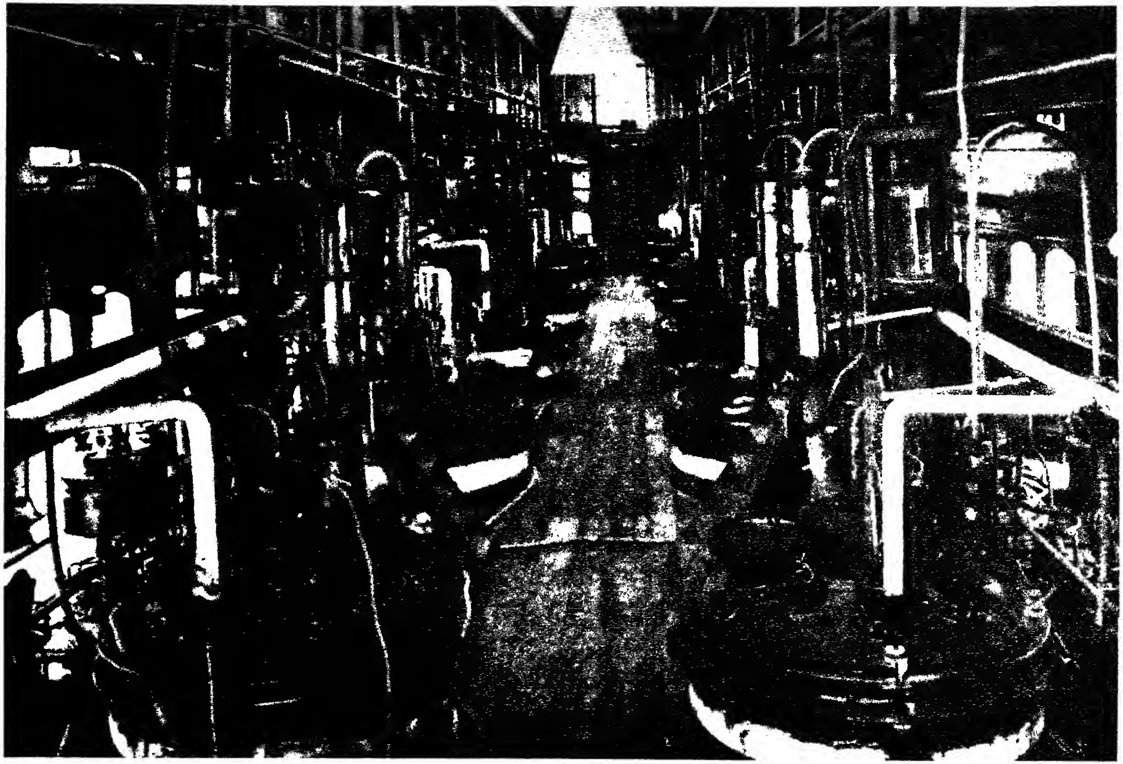


FIG. 16.—Corner of a chloracetic acid plant at Gersthofen, Germany (courtesy of *Das Spezial Archiv der deutschen wirtschaft*).

33,808 employees. The definition of the term "chemical," and especially the determination of what is a "plant," is not sufficiently explained to permit stating the precise departures from the terms "chemical" and "establishment" as used by the census. Obviously these figures give no clue to the number of employees per company, for, as was shown in the last chapter, E. I. du Pont de Nemours & Company, Inc., alone give work to about 47,000 employees, or nearly as many as the total for all the 578 plants canvassed here. Table 51 shows the details.

TABLE 51

SIZE OF PLANT IN THE CHEMICAL INDUSTRY IN 1934*

Number of Employees	Percentage of Employees	Percentage of Establishments	Number of Plants	Number of Employees
No employees ...	0.0	3.3	20	
1–5	0.4	13.7	82	246
6–20	2.9	25.3	151	1,752
21–50	7.3	22.2	133	4,363
51–100	9.2	13.2	79	5,544
101–250	19.0	12.0	72	11,410
251–500	17.5	5.2	31	10,493
500–1,000	26.1	3.8	23	15,660
1,001 or over	17.7	1.2	7	10,645
Total classified	100.0	100.0	598	60,113

* Compiled from figures of the National Industrial Conference Board given by *Chemical and Metallurgical Engineering* (January 1935), Vol. XLII, No. 1, pp. 4 and 5.

From these figures the fact emerges clearly that the sulfuric acid industry shows considerable contrast in type of plant from small to very large, from simple, almost batch, operations involving a modicum of hand labor to complicated, automatic operations involving scarcely any labor at all. Figure 16, while not specifically showing a sulfuric acid plant, presents a picture entirely similar to that in a modern sulfuric acid plant. The first impression gained upon visit-

ing such a plant is that the gigantically long and high lead chambers, the tall towers, the large cylindrical mechanical roast ovens, turning slowly but incessantly by electrical power, the acid eggs, and the tank cars, interconnected by a network of large and small pipes, combine to form a colossal mechanism with a will of its own, in the vastness of which the occasional laborer, it is felt, must be lost and overawed, if not in danger.

Modern plants of 100 to 150 tons a day capacity can be "controlled from one central room which contains the recording and indicating pyrometers, gas analytical instruments, etc. . . . . Only one operator with a helper for wheeling sulphur, oiling motors, etc., is required per shift."[2] After being put on a proper working basis, plants frequently operate for weeks at a time without further regulation and require only "one man per 12-hour shift, 7 days per week, and a helper in daytime, 10 hours per day, 6 days per week, or a total of 3 men."[3]

Plants vary in labor requirements not only because of differences in size, extent of capacity operated, and geographical location but also because of the process used, whether chamber or contact. Many chamber plants, especially those constructed some years ago by fertilizer companies, producing 100 tons of 50° Bé. acid per day, will require a furnace man, a niterman, and a pumpman twenty-four hours a day. On the day shift there will be one repairman and two laborers. While the force needed in a contact plant will vary with the local conditions, frequently, especially in some of the plants put up a few years ago, a larger proportion of skilled and trained men is necessary. In many units capable of

[2] William M. Grosvenor, "Sulphuric Acid," in Allen Rogers (ed.), *Manual of Industrial Chemistry* (2 vols., van Nostrand, New York, 1931), Vol. I, chapter iv, p. 174.

[3] P. C. Hoffmann, "Progress in Sulphuric Acid Manufacture," *Chemical and Metallurgical Engineering* (July 1926), Vol. XXXIII, No. 7, p. 407.

burning one-half a ton of sulfur per hour, i.e., producing roughly fifty tons of 50° Bé. acid per day, there are required on each shift a foreman, a burner man, an engineer, a fireman, and an absorber-house man, who also attends the scrubbers. Three men—a millwright, a pipe fitter, and an electrician—attend to maintenance. Unskilled labor is used as needed for handling the sulfur, pyrites, and coal, for packing the filters, for removing ashes and cinder—in short, for doing general janitor work.

IMPORTANCE OF QUALITY OF LABOR

From the foregoing the conclusion should not be drawn that labor in the sulfuric acid industry is altogether unimportant, for although the labor costs are a relatively small item and the number of laborers per unit of plant is similarly small, the quality of the personnel should be definitely first-class. Even in the operation of a chamber plant there has to be considerable precision of performance in order to obtain the high yield, low nitrogen consumption, and maximum daily tonnage requisite for maximum economy. If pyrites ore is used, it should be ground to a fineness of from 1/20 inch to 1/4 inch without excessive formation of dust, or there will be a sticky mass clinging to the rabbles of the furnace instead of a cleanly burning ore. Moreover, the time of rabbling must be varied, the speed of the fans changed, and the amount of air introduced directly into the hearths by the blowers increased or decreased from time to time so as to secure complete combustion of the sulfur without sublimation. Accurate and careful weighing, testing, and recording of acid shipped or used, of sulfur or other material charged, and so on, is essential. Moreover, the proper ratio of heat to the volume of nitrous vitriol and chamber acid entering the Glover tower must be maintained if complete denitration and minimum loss of nitrogen is to be secured. Leaks must

be observed, stopped, and reported promptly. Finally, continuous records of pressures and temperatures and frequent regular analysis of the gases and circulating acids are essential.

The superintendent of the acid department of the United Zinc Smelting Corporation ably summarizes the considerations of significance in this connection as follows:

> Personnel in an acid plant is much more important than commonly supposed. . . . . The use of mediocre operators will usually result in poor yield. . . . . In order to secure efficient men who will stay on the job month after month it is absolutely necessary to pay fair wages and to provide hours that do not make the operator an automaton who walks the chambers, writes down the results and makes no use of them, waiting only for his relief to come on so he may go home. In addition to paying fair wages it will, almost without exception, pay any company well to furnish an extra incentive in the form of a bonus based on a certain niter consumption per pound of product, a certain yield or both. . . . . Chambermen by careful work and co-operation are able to benefit personally, at the same time saving money for their company.[4]

The types of skill required in the office and in the plant are diverse. Inasmuch as the producer, even of sulfuric acid and notably of the many technical specialties whose production is commonly allied with it, must supply physical and chemical data, compatibilities, typical formulae, and so on, to cover the applicability of his products to a certain field, he has to have on his staff "a technical service man [who] is a demonstrator, a liaison officer between research-production and the ultimate consumer, both the forerunner and the supporter of the salesman."[5] Depending on the amount of integration, both vertically and laterally, his requirements of

[4] A. T. Newell, "High Points in Operating a Chamber Sulphuric Acid Plant," *Chemical and Metallurgical Engineering* (October 1927), Vol. XXXIV, No. 10, p. 609.

[5] L. A. Watt, "Technical Servicing for Chemical Products," *Chemical and Metallurgical Engineering* (January 1935), Vol. XLII, No. 1, p. 14.

laborers will vary from the minima mentioned above to a range of skills which will include—to name only a few—pipe fitters, stationary engineers, masons, carpenters, coopers, blacksmiths, locomotive engineers, trainmen, truck drivers, laboratory assistants, miners, ceramics and glass technicians, locksmiths, plumbers, and electricians, in addition to the usual clerical force in the office and sales force in the field.

The importance of quality of personnel is easily underestimated by the chemical layman. But to the chemical executive the fact is so well known that under the NRA a special clause was put into the Chemical Code, stating:

> The present products of this industry should be regarded only as by-products; its main product and purpose the extension of chemical knowledge in the public interest. It is recognized that the chemical industry if it is to keep abreast of chemical progress in the world, requires employees capable of constant advancement in their technical skill and of high and loyal character.

In an industry where new uses, new substitutes and new processes appear continuously, competitive strength in sum depends not so much on plant and equipment (though price may), but first and foremost on personnel, on resourcefulness, and on chemical knowledge in the executive offices, in the research laboratory, and in the plant.

HEALTH HAZARDS IN THE SULFURIC ACID INDUSTRY

The major risks of accident to which employees in the sulfuric acid plant are subject are the same as those in other factories, namely, injuries due to falling objects, wounds and contusions from the handling of sharp or heavy materials, falls from ladders and on slippery and uneven floors, electrical burns, getting caught in mechanisms such as engines and hoisting and conveying apparatus, and so on.

In addition, however, there are specific risks due to the

chemical nature of the process—acid burns, poisonous vapors, dusts, gases and fumes, explosions, and the like.

Acid burns are so common that a prominent technician recommends as follows: "Shower baths, where the full stream is released by one turn of the handle, frequently inspected, should be placed at convenient intervals. When a man gets acid on himself, he wants water, and he wants it in a hurry."[6] Solutions of baking soda, or lime water, and a 3 per cent solution of borax with an eye cup are also kept handy, usually in first-aid cabinets.

In the sulfuric acid industry proper the commoner poisons are:

1. Sulfuric acid vapor, which may inflame the respiratory organs and cause injury to teeth through softening of the dentine and chronic catarrh.
2. Sulfur dioxide, which irritates the mucous membranes of the respiratory organs and the eyes and causes digestive disturbances and spasmodic cough.
3. Sulfuretted hydrogen, especially around pyrites burners, which may cause vertigo, nausea, sallow complexion, emaciation, and conjunctival catarrh.
4. Nitrous gases and nitric acid, around the Glover and Gay-Lussac towers and in the chambers, especially in plants that "pot" the niter, which not only irritates the air passages, inflames the eyes, and corrodes the teeth, but may cause erosion and perforation of the nasal septum.
5. Lead, which causes the skin to turn a sallow yellow and brings about anorexia, lead line, asthenia, lassitude, arthralgias, and neuritis and in severe cases results in lead paralyses and atrophy of the optic nerve.
6. Hydrochloric acid, which not only irritates the mucous

[6] Philip de Wolf and E. L. Larison, *American Sulphuric Acid Practice* (McGraw-Hill, New York, 1921), p. 214.

membranes but may cause conjunctivitis, coryza, dental caries, and bronchial catarrh.

7. Arsenic, which may cause headaches, melancholia, gastric disturbances, skin diseases, melanosis, bleeding gums, multiple neuritis, and even paralysis.[7]

The longer the list of products made in a sulfuric acid plant, the greater the variety of poisons likely to affect the workers. Those just enumerated represent the minimum.

The danger of explosion comes particularly in loading or unloading the acid for purposes of transport. If sulfuric acid has been shipped in an iron tank, for example, hydrogen gas may have formed by action of sulfuric acid on the steel body of the tank. Any light except that of an electric flashlight or a circuit electric light with gas-proof socket and connection may be fatal. If it becomes necessary to enter a tank, gas masks should be worn and the man lowered into the tank by a rope so that he can be drawn up at the first sign of danger. In tanks that have hauled mixed acid, there may be niter gas, which is the more insidious because it is inoffensive to breathe—yet several hours later the worker who has breathed it may be dead.[8] The amount of caution necessary in this connection is well illustrated by the fact, for example, that in unloading a car of mixed acid, if the acid valve is removed before the air valve, any slight pressure which may have developed during transit within the tank car will cause the acid to spout out of the orifice into the face and arms of the worker.

Even in handling carboys a great deal of care is necessary. Acid should not be poured out as one pours water from a jug, but forced out through a glass tube by means of

[7] This section condenses considerably the information given by Louis I. Dublin, "Occupation Hazards and Diagnostic Signs," *Bulletin of the United States Bureau of Labor Statistics No. 306* (Washington, D.C., 1922), pp. 21–27.

[8] Merrimac Chemical Company, *Industrial Chemicals* (privately printed, Boston, no date), pp. 80–81.

a small hand pump and emptied by use of a carboy inclinator or siphon. Spilling means burns. Moreover, in storing the carboys one must keep them away from rags and rubbish and even from wooden buildings, or fires will start. They must be stored away from heat, or from steam pipes, and even out of reach of the rays of the sun; else vapor may form and explode the cork, causing a shower of acid and fume that will endanger workmen and plant.

Obviously workmen must be taught a host of safety habits, such as keeping respirator, goggles, leggings, and gloves clean; repeatedly washing hands and face and not wiping off perspiration or moisture on handkerchiefs and towels except after a preliminary washing; scrupulously cleaning up everything spilled, especially salts or liquids of a deleterious nature; doing no smoking, lighting of matches, or throwing of cigarette butts except out of doors; meticulously keeping every tool, ladder, bucket, or other object in its place out of aisles and passageways; using all safety devices such as life-lines, safety vapor-proof electric light globes, and so forth; refraining from sweeping floors, walls, or machines during working hours; and attending immediately to every cut, burn, or bruise, no matter how slight it seems.

Despite the many hazards in the sulfuric acid industry the number of accidents is not unusually high. This is due to the fact that employers have taken unusual pains to educate the worker. There are, of course, a few plants that do not measure up to the generally high standard. Thus, the Industrial Commission of New York reports:

> The average workman met with in certain chemical plants knows little or nothing of the nature or effect of the substances which he constantly handles, this ignorance being fostered by some manufacturers for the purpose of protecting their secrets from their competitors, or keeping the men at work in positions which they would refuse to hold if they realized the dangers of their occupations. Many of the materials are referred to only as "dope," "stuff,"

"liquor" or by initials which have no relation to the name or real composition of the material.[9]

But such practices not only run counter to the sensibilities of the overwhelming proportion of business men but have also been definitely proved extremely costly. The Committee on Safety and Production of the American Engineering Council has long since shown that "maximum productivity is dependent upon the reduction of accidents to an irreducible minimum." As part of a larger survey comprising the experience of 14,000 plants, they found in the case of three large companies manufacturing acids and heavy chemicals that "an increase of 24 per cent . . . . in the production rate from 1921 to 1925 . . . . was accompanied by a decrease of 43 per cent in the accident frequency rate and also a decrease of 48 per cent in the accident severity rate."[10]

The success is shown in humanitarian terms by the reports of the National Safety Council. In 1935, for example, only 13.5 per cent of the accidents in the chemical industry were due to contact with chemicals, 26 per cent occurred in connection with handling objects such as barrels and cases, 18 per cent consisted of falls of the person, and 11 per cent were wounds incurred in handling machinery. The chemical industry has long ranked with the top ten or twenty safest industries, having in 1925 a frequency rate per million hours' exposure of only 20.91,[11] a fifth of that (99.99) in mining, less than a third of that (69.54) in construction, and less than half of that in woodworking, quarrying, or meat packing and tanning—in fact, some 30 per cent less than the general

[9] State of New York, Department of Labor, *Special Bulletin No. 96, Health Hazards of the Chemical Industry* (Albany, 1919), p. 9.

[10] J. E. Hannum, "Safety and Production in Chemical Engineering Industries," *Chemical and Metallurgical Engineering* (October 1927), Vol. XXXIV, No. 10, p. 602.

[11] United States Department of Labor Bureau of Labor Statistics, *Bulletin No. 425, Record of Industrial Accidents in the United States to 1925* (Washington, D.C., 1927), p. 113.

average for all industries. The accident severity rate, on the other hand, was 2.71 days lost per 1,000 hours' exposure (where death and permanent disability are counted as 6,000 days lost, the loss of an arm 4,000 days, the loss of an eye 1,800 days, and so on). This was less than a third of that in mining, less than half of that in construction, quarrying, and cement, and but 30 per cent more than the average for all industries.

Among the chemical industries, the sulfuric acid industry is by no means the most dangerous. In fact, its accident frequency rate is lower than that for chemicals as a whole, being 7.32 in 1935, according to the reports of the National Safety Council, while that for chemicals in general was 9.53. It seems surprising that the accident frequency rate should be highest for the salt industry (30.46), followed by fertilizers (25.33), vegetable oil manufacturing (19.79), pharmaceuticals (17.11), coal-tar distilling (16.59), soap (13.84), paint and varnish (8.43), dye manufacturing (6.65), explosives (6.40), plastics (5.89), photographic film and chemicals (5.55), and carbon products (3.96). In short, it seems that accident frequency in the chemical industry exhibits to some extent a well-known feature of automobile accidents; namely, that they happen relatively less frequently where the dangers are best known.

WAGES AND HOURS OF LABOR

Wages in the sulfuric, nitric, and mixed acids industry have been consistently about 20 per cent higher than the level of wages in manufacturing industry generally. In Table 52 are contained some rough computations derived from census figures on number of wage earners and wages paid. These figures indicate precisely what one would expect when the character of the work is considered.

Sulfuric acid plants need considerable ground space for

the various kinds of complicated equipment used, since pumping and conveying materials to second or third floors is expensive. As has already been noted, they are usually located in some isolated section, near a large market to be sure, but nevertheless far enough away from the city to

TABLE 52

WAGES IN THE SULFURIC ACID INDUSTRY COMPARED WITH GENERAL MANUFACTURING, 1899–1927*

Industry	1899	1904	1909	1914	1919	1921	1923	1925	1927
General manufacturing	426	477	518	580	1,158	1,180	1,250	1,280	1,300
Sulfuric, nitric, and mixed acids...	560	620	660	720	1,600	1,460	1,470	1,410	1,640

* Data computed from figures on number of wage earners and total wages paid given in Bureau of Census reports on "Sulphuric, Nitric, and Mixed Acids" for the respective years.

make access to its conveniences expensive, if not somewhat difficult. Often a separate company town is built up, similar to mining towns. Thus the General Chemical Company has built homes for the workers at Bay Point, California; Capleton and Sulphide, Canada; and Pulaski, Virginia. At Marcus Hook, Pennsylvania, a complete settlement, Overlook Colony, was established with schools, theaters, and so forth. Moreover, the work must be carried on in an atmosphere that is frequently repulsive and sometimes injurious. The worker is continually exposed to gases and fumes that poison and inflame the eyes and lungs. Corrosive liquids must be handled. The allurement of higher wages would therefore seem to be necessary to attract labor from less hazardous occupations.

Such explanations, however, do not stand up under more complete analysis. It is believed by many men in the trade, for example, that wages per hour are less than in other industries. Precisely because work in the sulfuric acid industry is less agreeable than labor of similar skill and

quality in other trades, the more competent men tend to remain in the other industries, while the culls, so to speak, the unlettered immigrant, and others of that great number of unskilled laborers to whom having a job is so necessary that unfavorable conditions are not scrutinized closely, even when known to exist, are pushed down by competition into the sulfuric acid industry.

If that be true, how explain the higher wage? The answer given is twofold. In the first place, practically all the workers in the sulfuric acid industry are men, while in general manufacturing over 20 per cent of the wage earners are women and children. In 1909, for example, in the sulfuric, nitric, and mixed acids industry, out of a total of 2,617 employees, only 35, or 1.4 per cent, were females. Of the males 2,252, or 87.2 per cent, were wage earners, while 8.7 per cent were clerks and 4.1 per cent were officials. There is very little child labor in the chemical industry. Consequently, the average yearly wage in the sulfuric acid industry is not brought down by low figures for children's wages. Furthermore, as is shown in Table 53, below, more hours used to be worked per day in the sulfuric acid industry than in general manufacturing. Notice that the percentage working less than 54 hours a week has been consistently and considerably higher in general manufacturing than in the sulfuric, nitric, and mixed acids industry. But the story is otherwise when the figures of percentages working more than 60 hours are considered. Thus, for example, in 1923 only 2 per cent of the workers in general industrial enterprise labored over 60 hours a week, while nearly ten times that proportion had a week more than 60 hours long in the sulfuric acid industry. Over three times as large a percentage worked from 54 to 60 hours a week as in general manufacturing. This is, of course, easily understood. Continuity of operation is the *sine qua non* of cheap production

and uniform quality. Technologically and financially it is extremely desirable that the plant be kept going twenty-four hours a day. Moreover, the work is fairly easy, most of the hard labor being done by mechanical devices, while the main function of the operative is that of being watchman, recorder, manipulator of valves, pumps, cranes, and so on. Hence, both the total yearly wage and the rates per hour are higher in the sulfuric acid industry than in industry generally.

TABLE 53

COMPARISON OF LENGTH OF WORKING DAY IN THE SULFURIC ACID INDUSTRY WITH THAT IN GENERAL MANUFACTURING, 1909–1923*

Year	Percentage of Employees Working Under 54 Hours a Week		Percentage of Employees Working 54 to 60 Hours		Percentage of Employees Working 60 Hours		Percentage of Employees Working over 60 Hours	
	All Industries	Sulfuric, Nitric, and Mixed Acids	All Industries	Sulfuric Acid	All Industries	Sulfuric Acid	All Industries	Sulfuric Acid
1909....	35	9	30	2	30	25	5	64[a]
1914....	49	8	22	12	21	16	6	64
1919....	74	53	14	29	9	4	3	14
1921....	78	43	13	47	7	6	2	4
1923....	77	29	14	46	7	6	2	19

* Bureau of the Census reports for the years indicated.

[a] 38.5 per cent of the workers labored over 72 hours per week.

The facts concerning labor since 1927 lie hidden in the statistics on "chemicals not elsewhere classified," but they probably do not differ considerably therefrom. Consequently, in Figure 17, a summary picture is given of the chemical manufacturing industry since 1926. An outstanding revelation of this chart is the relatively high hourly wage rates, rising in 1936 to more than 65 cents per hour; that in all factories is about 57 cents. Furthermore, the average weekly earnings have been steadily maintained, never getting down below $22.50 a week during the depression, whereas that in all factories reached a low of $16.00. And

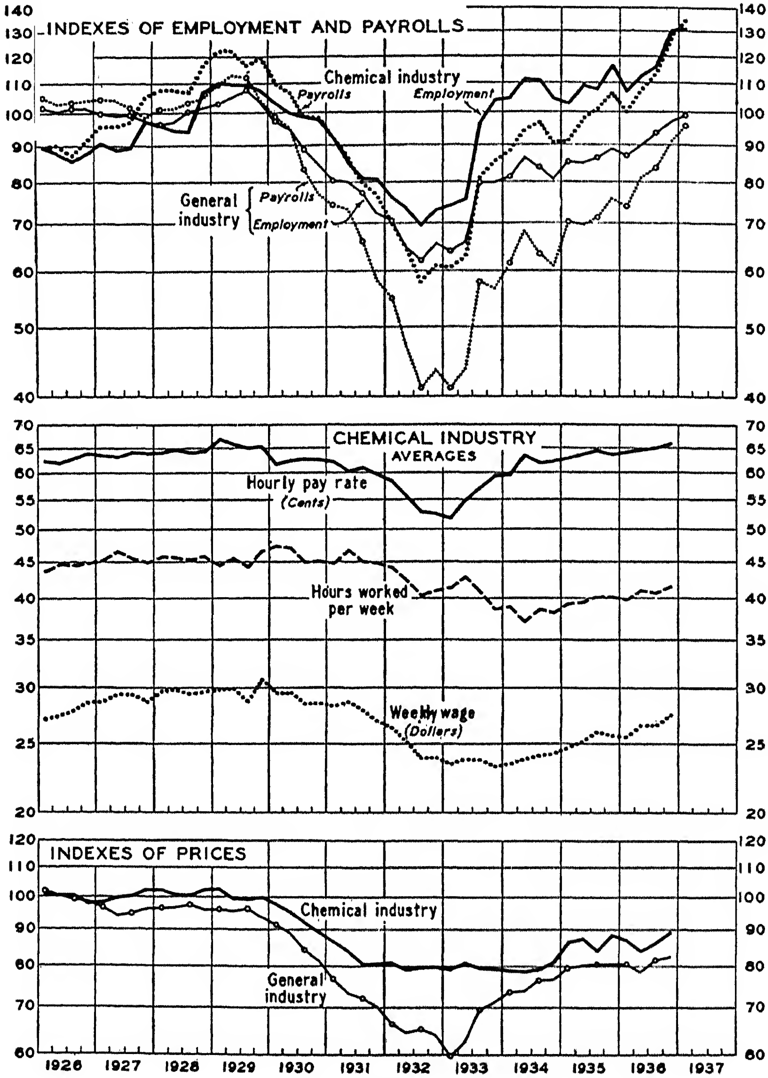


FIG. 17.—Labor in the chemical industry, 1926–1937. Data taken from monthly bulletins on Employment and Payrolls and on Wholesale Prices published by the United States Bureau of Labor Statistics. The price index for the chemical industry is that of the subgroup "Chemicals" under "Chemicals and Drugs."

at the end of 1936 the average weekly earnings in chemical plants was nearly $27.00, whereas that in factories generally was about $23.00. Notice in particular that early in 1934 the index of employment in chemical plants began to exceed 1929 levels and in 1936 rose to a point nearly 40 per cent higher. When payrolls are compared, the same fact appears, the index of payrolls in chemical plants consistently maintaining a level from ten to fifteen points above the index for manufacturing in general. Probably the most remarkable fact shown is that prices of chemicals have not risen a great deal despite the fact that the chemical industry pays out higher rates of wages per hour and more dollars per week for less hours than does manufacturing generally. This has been the history of the industry for a long time: it pays good wages in order to attract dependable men.

SUMMARY

The short survey of labor conditions in the sulfuric acid industry made in this chapter indicates the kind of change to be expected from a wider spread of the chemical phase of the Industrial Revolution. In order to secure maximum yield, greatest economy of materials, and expert supervision of processes, the demand for skilled technicians increases. Physical productivity per worker also increases. Owing to the chemical nature of the materials handled, the hazards of enterprise are increased, which constitutes another factor increasing the demand for intelligent labor scrupulously carrying out safety precautions. Processes, moreover, are more automatic and continuous, which means more clerical labor, and possibly a tendency to keep the length of the working day from decreasing as rapidly as it otherwise might. These are some of the effects so far as labor is concerned which flow from the pervasion of industrial practices by chemical science.

XII. Intercommodity Competition and the Outlook for Sulfuric Acid

In the preceding chapters the requirements of exposition made necessary on more than one occasion a mention of one or other important use of sulfuric acid, but always in general terms. The information thus far given can readily be summarized by saying that in ordinary years the most important outlets for sulfuric acid in order of volume of consumption are: fertilizers, which usually take between 25 and 35 per cent of the whole supply; petroleum refining, taking about 20 per cent; chemicals, consuming about 10 per cent; the by-product coke industry, consuming another 10 per cent; the cleaning (pickling) of iron and steel preparatory to galvanizing, taking somewhat less than 10 per cent; other metallurgical processes, taking roughly 8 per cent; and a variety of other uses, including paints, pigments, rayon, and textile-processing, taking the remainder, that is, from 10 to 15 per cent.

But an explanation of the uses of sulfuric acid in detail, a description of the way in which sulfuric acid reaches these markets, how it is consumed, what competition it meets, and what the potentialities and outlook are in the various consuming industries—these are tasks as yet unaccomplished to which we now devote attention.

Chemically, sulfuric acid serves four main purposes. Most important of all, of course, is its use as an acid, whereby because of its strength and cheapness it finds wide use—in making other acids; in acidulating phosphate fertilizers; in producing sulfates such as alum, blue vitriol, copperas, and ammonium sulfate; in cleaning iron surfaces for tinning and galvanizing; in converting starch into invert sugar and making glucose and syrup; in producing parch-

ment paper from cellulose; and in manufacturing accumulators for the generation of electric current. Next most important is its use as a dehydrating agent, whereby, owing to its great avidity for water, it chars and separates mucilaginous constituents out of oil and thus aids in the manufacture of gasoline, kerosene, and so forth. It produces a finely divided carbon out of treacle, thus making shoe blacking. It brings about the esterification reactions in glycerine necessary, with nitric acid, to make nitroglycerine and thus helps to produce the nitrocelluloses that go into the making of collodion and guncotton; by this means also is made possible the nitration of organic compounds, such as toluene, from which is produced the high explosive, TNT; benzene, which ultimately yields aniline; and phenol, from which picric acid, that is, lyddite or melinite, is manufactured. In the third place, sulfuric acid is used for the purpose of sulfonation in making coal-tar chemicals. Finally, it is an effective oxidizing agent, as, for example, when naphthalene heated with fuming sulfuric acid in the presence of mercury as a catalyst is oxidized to phthalic anhydride, which is the starting point for the synthesis of indigo. Sulfuric acid is thus not only the cheapest and most powerful of acids but is a dehydrating, sulfonating, and oxidizing agent as well.[1]

IMPORTANT USES OF SULFURIC ACID

Perhaps in no respect are the effects of the chemical penetration of business more apparent and more beneficial than in multiplying the uses to which a given article can be put. This is again well illustrated in the sulfuric acid industry. Indeed, "several hundred specific uses of sulphuric acid in

[1] This paragraph leans heavily on the detailed explanation given by J. R. Partington, in *The Alkali Industry* (van Nostrand, New York, 1919), especially Section X, "Utilization and Economy of Sulfuric Acid."

the chemical, allied, and other industries can be enumerated without difficulty and without exhausting the subject, a fact significantly expressive of the all-importance of this most basic of all chemical products."[2] An English technologist of distinction states: "There is scarcely a manufactured product known, in the preparation of which, either of the raw materials or in the actual process of making the article, sulphuric acid does not play a part."[3] No attempt will, therefore, be made to enumerate them.[4]

Even to enumerate only the principal applications of the acid is a long, detailed, tiresome, but instructive task. Sulfuric acid of 50° Bé. up to 60° Bé. strengths is used in making salt cake, hydrochloric acid, soap, superphosphates, and other artificial manures, and sulfurous, nitric, phosphoric, hydrofluoric, boric, carbonic, chromic, oxalic, tartaric, citric, acetic, and stearic acids; in preparing iodine, bromine, the sulfates of potassium, ammonium, barium (blanc fixe), and calcium (pearl hardening), also the sulfates of magnesium, aluminum, iron, zinc, copper, and mercury (as an intermediate stage for calomel and corrosive sublimate); in the metallurgy of copper, cobalt, nickel, platinum, silver; for cleaning sheet iron to be tinned or galvanized, also copper, silver, and so forth; for manufacturing potassium dichromate; for galvanic cells, storage batteries; for manufacturing ordinary ether and the composite ethers; for making parchment paper; for the purification of many mineral oils and sometimes of coal gas; for manufacturing starch, syrup, and sugar; for neutralizing the alkaline reactions of fermenting liquors, such as molasses; for preparing tallow previous to melting it; for recovering the fatty

[2] United States Tariff Board, *Chemicals, Oils and Paints. Glossary on Schedule A* (Washington, D.C., 1912), p. 15.

[3] J. R. Partington, *op. cit.*, p. 262.

[4] For an extended list, see Georg Lunge, *The Manufacture of Sulphuric Acid and Alkali* (3 vols., 3 ed.) (London, 1903), Vol. I, Part II, pp. 1169 ff.

acids from soapsuds; for destroying vegetable fibers in mixed fibers; generally, in dyeing, bleaching, mordanting, calico printing, and tanning; in medicine against lead poisoning, and in many other cases. Sulfuric acid of 66° Bé. strength is used for the manufacture of fatty acids by distillation; for purifying benzene, petroleum, paraffin oil, and other mineral oils; for refining gold and silver and for desilverizing copper; for making organic sulfonic acids; in the manufacture of coal-tar dyes, pyroxylin plastics, explosives, rayon, and celluloid; and for making nitric-acid compounds and nitroethers in general. Oleum is required for the manufacture of many organo-sulfonic acids used in the manufacture of certain dyes such as alizarin, synthetic indigo, and eosin, also for increasing the ordinary strength of sulfuric acid to higher concentrations. These are some of the main uses of the various grades of sulfuric acid.

CONSUMER-PRODUCER RELATIONS IN THE SULFURIC ACID INDUSTRY

The outstanding feature of marketing sulfuric acid is the fact that four-fifths of it is consumed by the chemical-process industries. As has already been indicated, most of it is sold direct, the manufacturer using his own tank cars and trucks, making deliveries in carload lots direct from the plant and in less than carload lots from spot stocks carried in his own warehouses. These stocks, however, are never very large, sulfuric acid being too dangerous and explosive to store. Even in the highly seasonal fertilizer industry, sulfuric acid is made when and usually where ready to be consumed. Only a small amount is sold through brokers, selling agents, or other distributors. Still less is sold through retail outlets. In 1929 according to the *Census of Distribution* published by the Bureau of the Census, of a total of 715 million dollars' worth of chemicals, only 1.7 per cent was sold to re-

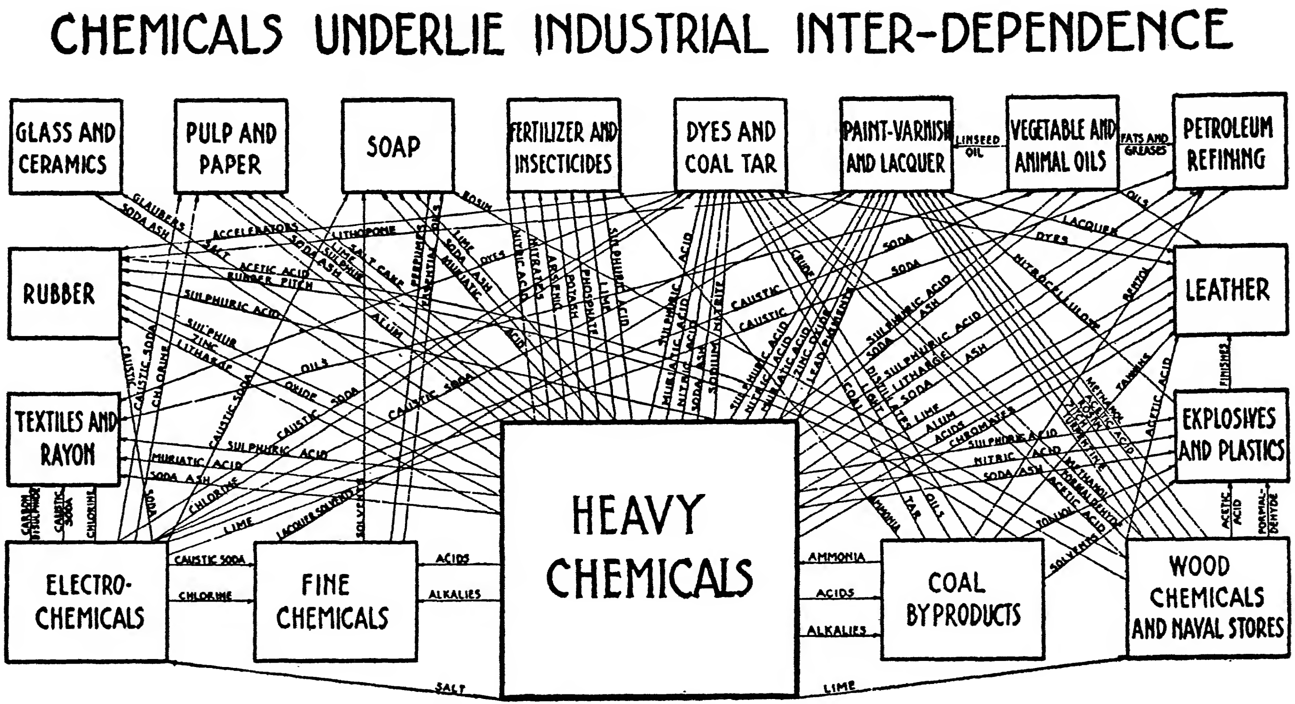


FIG. 18.—Joint and composite demand. From *Chemical and Metallurgical Engineering* (January 1928), Vol. XXXV, No. 1, p. 4.

tailers and 21.2 per cent to wholesalers, while 15.4 per cent was disposed of to branch wholesalers owned by the manufacturers and 61.7 per cent was sold direct to industrial consumers.

The interrelationship of the marketing of sulfuric acid with that of other products is excellently shown in Figure 18. Sulfuric acid is merely one of the many products which the manufacturer sells to the industrial purchasing agents of industries utilizing chemical processes. Being jointly demanded with other products, it represents in most cases but a small part of total raw material expense; hence the demand for it is frequently thought to be inelastic and its price a matter of relative unimportance. Consumer-producer relations, instead of being anonymously carried on through the market with price an important determinant, are personal, direct, and technical, depending not on the kind of good will or preference built up through general advertising but on that created by satisfactory personal relationships between the salesman and the purchasing agent or foreman of the department using the chemical. Good will is, of course, maintained by satisfactory deliveries in time and quantity, and is guaranteed by complete contract understanding of quality specifications, of methods of sampling and testing deliveries, of requirements as to containers, and of price and other terms and conditions of sale.

In recent years the increasing complexity of the uses for sulfuric acid and other chemicals and the increasing substitutability of products, i.e., intercommodity competition, has led the larger manufacturers to give a considerable place in the sales organization to technical service men or "trouble shooters," specialists familiar enough with buyers' products and processes to be able to recommend the specific quality and quantity of chemical product that is best adapted to users' needs and pocketbook.

The technical service man is usually supplied with facts by the commercial research department,[5] which is continuously increasing the company's knowledge of the properties and qualities of its products, their potential market volume and outlets, potential competition, and so on. He is frequently the first representative of his company to visit a prospective customer, paving the way for the regular salesman, and distributing company literature on products and their suggested uses. Once his company's line of merchandise is adopted, his job becomes one of teaching the user how to get the best results and rendering whatever technical service is necessary to assure maximum user satisfaction. This not only may mean "trouble shooting" but may involve the designing of equipment and the supplying of "necessary engineering and complete working drawings,"[6] in which case frequently a small service charge is made. He is in a particularly strategic position to suggest improvements. He keeps the research department of his company *au courant* with customer problems.

As has already frequently been intimated, by far the most important limitation on marketing sulfuric acid is the difficulty of transporting it. The Interstate Commerce Commission rightly classifies it as a corrosive liquid and has accordingly promulgated strict regulations for its shipment: "Unless dangerous articles are transported in company-owned trucks and boats or by carriers not engaged in interstate transportation [this requires that users have storage facilities] they must be packed in containers specified by the regulations."[7] So far as sulfuric acid is concerned, these containers, for small amounts, are glass carboys holding about

[5] C. L. Burdick, "Does Customer Research Pay?" *Chemical and Metallurgical Engineering* (January 1935), Vol. XLII, No. 1, p. 10.

[6] L. A. Watt, "Technical Servicing for Chemical Products," *ibid.*, p. 15.

[7] R. W. Lahey, "Containers That Serve Customers," *ibid.*, p. 17.

180 pounds of 66° Bé. acid usually enclosed in wooden boxes and packed in hay; for somewhat larger amounts, light sheet-steel drums holding from 500 to 1,500 pounds of acid; and for large amounts tank wagons or tank cars, the latter having capacities varying from 60,000 to 160,000 pounds. All must be plainly marked with white head and black body and labeled with a white label.

Being compelled to use costly returnable containers, the manufacturer of sulfuric acid frequently finds it worth time and money to educate his customer's employees in handling and emptying his product. He frequently also requires a deposit which is returned or credited if the container comes back undamaged, a factor which, even in the absence of controversy concerning responsibility for damage, increases his marketing expense by certain intangible costs of accounting, billing, and wear and tear on containers.

The cost and difficulty of transport being of such considerable magnitude, especially for the dilute or 50° Bé. acid, many large-scale users, especially the manufacturers of fertilizers, make their own acid. In Table 54 the fact appears clearly that the percentage consumed where made has been going down steadily, owing mainly to the decline in importance of the fertilizer industry, from more than one-half to slightly less than one-third of the total. But it is still substantial.

JOINT DEMAND

It has frequently been stated that sulfuric acid is only one of many products used by the industries that consume it. The time has now come to provide detailed proof of this, for at least the most important outlets.

The fertilizer industry has since 1880 been the largest consumer, sulfuric acid being necessary to transform the insoluble phosphate rock into water-soluble plant food or

superphosphate. At first the acid-phosphate maker required only three structures: a shed to cover the rock pebble or untreated phosphate, a den in which to treat his mixtures, and a lean-to in which to package and store his product. "Harrows, hoes, rakes, and a screen were all the tools that he

TABLE 54

SULFURIC ACID CONSUMED WHERE MADE, 1889–1935*

Year	Sulfuric Acid Produced 50° Bé. Basis (*Thousands of tons*)	Sulfuric Acid Consumed Where Made (*Thousands of tons*)	Percentage Consumed Where Made
1889	784	291	37
1899	1,548	764	49
1904	1,869	968	52
1909	2,749	1,285	47
1914	3,790	1,733	46
1919	5,553	2,221	40
1921	4,370	1,666	38
1923	6,556	2,211	34
1925	7,004	2,304	33
1927	7,336	2,346	32
1929	8,491	2,675	31
1931	6,085	1,855	30
1933	.....[a]	.....[a]	..[a]
1935	6,462	1,992	31

* Bureau of the Census reports on "Chemicals" in the censuses of manufactures for the respective years.

[a] No data.

used. . . . . Today his plant which is designed by a chemical engineer contains a network of modern machinery and every step of the process is subject to the immediate supervision of a chemist working in a modern, well-equipped laboratory at the plant."[8] The point at which sulfuric acid is used in making superphosphate is shown in Figure 19, as are also the details of the process as a whole.

[8] R. B. Deemer, "Chemistry in the Fertilizer Industry," in H. E. Howe (ed.) *Chemistry in Industry* (2 vols., Chemical Foundation, New York, 1924), I, 114.

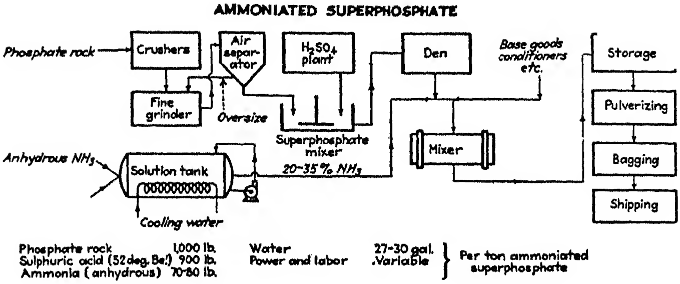


FIG. 19.—Sulfuric acid (H_2SO_4) in a fertilizer plant. From *Chemical and Metallurgical Engineering, Flow Sheets of Process Industries* (McGraw-Hill, New York, 1936), p. 57.

The raw materials consumed by the fertilizer industry in 1936 are shown in Table 55 below. Sulfuric acid, while by far the largest in tonnage, is clearly shown to be only one of the materials used. The fertilizer industry produced 4,600,000 tons of mixed fertilizer and 6,200,000 tons of fertilizer products in general.

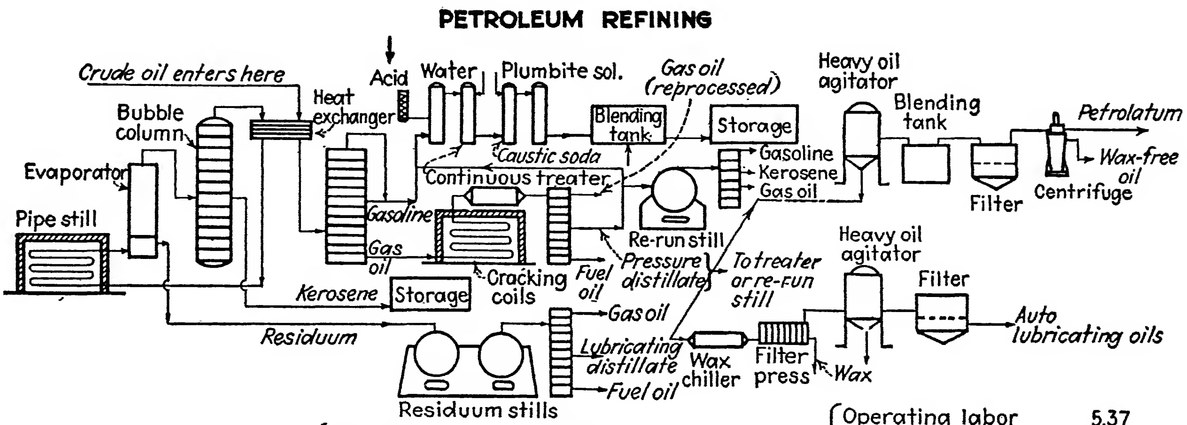
TABLE 55

MATERIALS CONSUMED IN THE FERTILIZER INDUSTRY IN 1936*

Raw Material	Quantity in Tons
Phosphate rock	1,980,000
Acidulated sulfuric acid (50° Bé.)	1,825,000
Bone meal and other phosphate carriers	40,000
Potash salts (muriate, sulfate, kainit, etc.)	620,000
Liming materials	55,000
Sodium nitrate	580,000
Ammonium sulfate	570,000
Other inorganic nitrogen carriers	310,000
Organic nitrogen carriers	340,000
Fillers	350,000

* *Chemical and Metallurgical Engineering* (February 1937), Vol. XLIV, No. 2, p. 72.

The second most important outlet for sulfuric acid in recent years has been the petroleum industry. But there, too,



Average yield in gallons from 1 bbl. (42 gal.) of Mid-Continent Crude Oil 1929 - 1930

Gasoline	20.63
Kerosene	2.63
Lubricants	1.52
Gas oil and fuel oil	14.18
Residuum	3.04

Total operating cost in cents per bbl. of charging stock

Operating labor	5.37
Fuel	4.52
Chemicals	4.82
Repairs, maintenance	3.66
Other direct	10.50
Overhead, insurance depreciation etc.	13.95
Total operating cost	42.82

(*From report of U.S. Tariff Commission, 1932, on Costs of Refining Petroleum Products*)

FIG. 20.—Sulfuric acid in petroleum refining. From *Chemical and Metallurgical Engineering, Flow Sheets of Process Industries* (McGraw-Hill, New York, 1936), p. 77.

"other products of organic synthesis have increased in importance to such an extent that sulphuric acid, caustic soda, and litharge, once the mainstays of the refining industry, now represent less than a fifth of the total expenditures for chemicals."[9] The consumption of sulfuric acid per barrel of gasoline has declined steadily since 1920 from 10 pounds, then worth about four cents, to 4½ pounds, or less than two cents' worth, in 1936. The annual consumption of sulfuric acid in this industry rose from about 530,000 tons 50° Bé. in 1919 to a peak of 1,480,000 tons in 1929 but has declined steadily since that time to about a million tons in 1936, despite the increased production of gasoline.

The use made of sulfuric acid is shown in Figure 20, the arrow indicating where it is added to the materials in process. The figures of the United States Tariff Commission indicate that the cost of sulfuric acid per gallon of gasoline is less than one-tenth of one cent. The function performed by the acid as shown on the chart is described in a technical treatise as follows:

> The most important quality required of gasoline is stability under conditions of marketing and use. This requires the absence of substances which form gum when gasoline is stored or burned. It is also often required that gasoline be free of color, sweet in odor, noncorrosive, sweet to the doctor (sodium plumbite) test, and with a sulphur content below a fixed maximum value. To enable cracked distillates to meet these requirements a number of treating methods have been developed, the one to be used in a particular case depending upon the specifications to be met and the oil used in cracking.
>
> [The following is] the "most desirable and most generally applied method for the treatment of cracked distillates
>
> "(*a*) Agitate with sulphuric acid. Settle and draw off sludge
>
> "(*b*) Short water wash, usually 5 to 10 minutes.
>
> "(*c*) Agitate with plumbite solution . . . .
>
> "Cracked distillates from mid-Continent charging stocks—includ-

[9] R. B. Deemer, "Chemistry in the Fertilizer Industry," in H. E. Howe (ed.) *Chemistry in Industry* (2 vols., Chemical Foundation, New York, 1924), I, 68.

ing those from northern and central Texas, Louisiana, Oklahoma, Kentucky and Kansas as well as those from the Rocky Mountain, Appalachian, and Indiana fields—usually require from 2 to 6 pounds of acid per barrel of distillate. Those from Texas coastal, Smackover (Arkansas), California, Mexican, South American, Borneo, etc., charging stock usually require 5 to 8 pounds per barrel of distillate."[10]

The other chemicals utilized in the petroleum-refining industry and some of the main products are shown in Table 56, below. Again it is evident that the demand for sulfuric acid is a joint demand, that it is used in amounts fixed by considerations of technology, and that, consequently, the amount demanded is inelastic and independent of price fluctuations, at least within moderate limits.

TABLE 56

CHEMICALS CONSUMED AND PRINCIPAL PRODUCTS, PETROLEUM REFINING*

Material Used	Quantity	Product	Quantity
Crude oil	966,240,000 bbls.	Gasoline	457,692,000 bbls.
Natural gasoline	38,964,000 bbls.	Kerosene	55,812,000 bbls.
Sulfuric acid (50° Bé.)	1,000,000 tons	Lubricants	27,768,000 bbls.
Caustic soda	96,000 tons	Gas oil and distillate fuels	100,380,000 bbls.
Soda ash	8,000 tons	Asphalt	3,252,000 tons
Fuller's earth	206,000 tons	Wax	225,000 tons
Lime	100,000 tons	Petroleum coke	1,464,000 tons
Sulfur	7,000 tons	Residual fuel oil	254,748,000 bbls.
Litharge	6,000 tons		
Calcium chloride	10,000 tons		
Organic solvents	4,800,000 gals.		
Gum inhibitors, dyes, organic stabilizers	$10,000,000 worth		

* *Chemical and Metallurgical Engineering* (February 1937), Vol. XLIV, No. 2, p. 72.

In the by-product coke industry, according to data published by the Bureau of Mines, roughly 49,000,000 tons of coal were treated, 577,000 tons of 50° Bé. sulfuric acid and

[10] Allen Rogers (ed.), *Manual of Industrial Chemistry* (2 vols., 5th ed., van Nostrand, New York, 1931), Vol. II, chapter xxvii, "The Petroleum Industry," by Gustav Egloff, pp. 882 and 884.

50,000 tons of lime were used[11] to produce 34,000,000 tons of coke, 543,000,000 million cubic feet of coke-oven gas, 450,000,000 gallons of coal tar, 462,000 tons of ammonium sulfate, 21,000 tons of ammonia, 134,000,000 gallons of crude light oil, and 13,000,000 pounds of naphthalene.

In that same year—to give but one more illustration of the manner in which the demand for sulfuric acid is a joint demand—the rayon industry used in addition to 309,000 tons of sulfuric acid[12] (50° Bé. basis), 73,850 tons of linters, 111,250 tons of sulfite pulp, 160,000 tons of 767 caustic soda (not counting that recovered), 45,700 tons of carbon bisulfide, 22,500 tons of glucose, 9,000 tons of pigments, 18,000 tons of glacial acetic acid, and 57,500 tons of other chemicals such as acetone, anhydrous ammonia, copper sulfate, sodium sulfide, hydrochloric acid, zinc salts, glycerin, bleaching materials, soaps, oils, and so forth.

PERCENTAGES CONSUMED IN VARIOUS INDUSTRIES

Before the World War more than one-half of the total sulfuric acid produced in the United States was consumed in the manufacture of fertilizers. The development of other uses caused this percentage to be cut in two during and after the war, though in absolute amounts in prosperous times the tonnage has fluctuated in the neighborhood of 2,000,000 tons. Table 57 gives the figures in detail, showing clearly that except for the year 1918, when abnormal quantities of sulfuric acid were taken by the explosives industry, and the depression year 1932 the fertilizer industry has always been the largest consumer.

The next largest consumer except for the year 1918 has always been the petroleum refining industry. During the

[11] Estimates of *Chemical and Metallurgical Engineering* (February 1937), Vol. XLIV, No. 2, p. 87.

[12] *Ibid.*, p. 94.

TABLE 57

Consumption of Sulfuric Acid by Industries, 1900–1936*

Year	Total Sulfuric Acid 50° Bé. Basis (*Thousands of tons*)	Fertilizers		Petroleum Refining		Chemicals		Coal Products		Iron and Steel		Other Metallurgical		Paints and Pigments		Explosives		Rayon and Cellulose Film		Miscellaneous, Including Textiles	
		Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage	Thousands of Tons	Percentage
1900...	1,548[a]	803	52	182	12	265[b]	17	14	1	125	8	...[c]	..	...[c]	..	13	1	...[c]	..	145	9
1909–11	3,250[d]	2,400	74	300	9	200	6	...[c]	..	200	6	...[c]	..	...[c]	..	150	5	...[c]	..	...[c]	..
1918...	7,510	2,130	28	671	9	740	10	...[c]	..	700	9	292	4	204	3	2,700	36	...[c]	..	75	1
1923...	6,600	2,070	31	1,200	18	1,000 th. tons 15%				700	11	500	8	198	3	200	3	...[c]	..	732	11
1924...	6,180	1,800	29	1,300	21	1,000 th. tons 16%				600	10	600	10	200	3	180	3	...[c]	..	500	8
1925...	6,853	1,975	29	1,450	21	1,100 th. tons 16%				725	11	700	10	200	3	185	3	...[c]	..	518	8
1926...	7,168	2,059	29	1,325	19	750	10	742	10	740	10	725	10	200	3	190	3	...[c]	..	437	6
1927...	6,935	1,925	28	1,350	19	725	10	732	11	685	10	700	10	210	3	183	3	...[c]	..	425	6
1928...	7,225	2,300	32	1,350	19	745	10	740	10	670	9	570	8	205	3	170	2	105	1	370	6
1929...	8,338	2,418	29	1,570	19	890	11	935	11	800	10	675	8	225	3	195	2	150	2	480	6
1930...	7,625	2,350	31	1,485	19	820	11	800	10	660	9	560	7	200	3	177	2	145	2	428	6
1931...	5,904	1,455	24	1,348	23	760	13	570	10	480	8	410	7	180	3	175	3	183	3	343	6
1932...	4,410	780	18	1,240	28	674	15	375	8	270	6	310	7	160	4	120	3	176	4	305	7
1933...	5,148	1,200	23	1,140	22	725	14	468	9	390	8	360	7	170	3	140	3	242	5	303	6
1934...	6,166	1,650	27	1,100	18	910	15	500	8	475	8	400	6	330	5	180	3	256	4	365	6
1935...	6,725	1,730	26	980	15	940	14	625	9	630	9	520	8	400	6	175	3	309	4	416	6
1936...	7,620	1,970	26	1,100	15	985	13	770	10	700	9	600	8	450	6	220	3	337	4	488	6

* Unless otherwise indicated, these are estimates of *Chemical and Metallurgical Engineering* published in the Annual Review number (usually the January issue), for the respective years.

[a] Data for 1900 from United States Department of Commerce and Labor, Bureau of Census *Bulletin No. 92* (Washington, D.C., 1908), C. E. Munroe, "Chemicals and Allied Products," Table 17, p. 23.

[b] Includes 71,426 tons used in the manufacture of alums, 63,059 tons for mixed acids, 48,750 tons for muriatic acid, 47,348 tons for nitric acid, 17,814 tons for acetic acid, 10,645 tons for blue vitriol, 1,503 tons for tartaric acid, 1,220 tons for iron liquors, 707 tons for boric acid, 415 tons for zinc sulfate.

[c] No data.

[d] Estimates of Utley Wedge in *American Fertilizer* (October 19, 1912), pp. 39–42. Under chemicals he includes gold and silver metallurgy, aniline, sulfates, acids, and ether. The author has listed under explosives Wedge's estimate for nitrocellulose, nitroglycerine, and celluloid. Wedge's iron and steel figure includes coke.

depression it held up considerably better than the fertilizer industry, with the result that in the year 1932, despite a declining trend in total consumption, it was the largest outlet of all. In the 'twenties it took roughly a fifth of the total acid produced, but in the last five years a series of improvements in refining technology have reduced its requirements of acid by more than 50 per cent per barrel of distillate.

The next largest consumer, the "chemicals not elsewhere classified" industry, normally takes from an eighth to a sixth of total acid produced. During the depression its consumption of sulfuric acid sank only a sixth below 1929 levels, whereas that of fertilizers and of the iron and steel industries sank two-thirds, and that of the explosives, paint and pigment, and miscellaneous industries about one-third.

Two other facts should be noticed. First, the substantial readjustment forced upon the sulfuric acid industry by the World War, especially the shift of usage from fertilizers to explosives, chemicals (i.e., dyestuffs and coal-tar products), and iron and steel pickling (i.e., the canning industry). Second, the rapid rise of consumption in the rayon industry without substantial setback even during the depression.

OUTLOOK FOR SULFURIC ACID

A characteristic of chemical industries is that in them forecasts are extraordinarily difficult to make. No matter how old and seemingly well established the industry, a host of technical and economic possibilities and probabilities beset the demand and supply of any one product. To evaluate these possibilities and probabilities is extremely difficult, and to predict which one or two may become all-important in the next five years is almost impossible.

Sulfuric acid is no exception. On every hand are fluctuations, shifts of relative advantage in the processes used,

variations in sources of supply and types of raw material, changes in the economic situation of the industries producing it, and potential competition in the various markets. To aggregate, integrate, and evaluate all these forces of demand and supply and make even a brief statement of outlook that is reliable is impossible. But it is likewise unnecessary. All that is required is a summary of factors as of the present time, with a mention of potentialities that may become significant realities.

Beginning with the factors of sulfuric acid supply, let us recall that at the present time the contact process is rapidly gaining competitive success over the long-established chamber process. Now vanadium catalysts have enabled contact plants almost to dispense with burner-gas purification systems. In addition, the X-ray treatment of catalysts, experimentation with silica gel as a carrier of platinum, and other developments may readily increase the average over-all conversion efficiency of sulfur into sulfuric acid under normal plant loading to a higher level than the 95 per cent figure now prevalent, which, of course, will mean cheaper sulfuric acid of concentrated strengths.

Whether or not the chamber process will be able to retain its hold on the production of 50° Bé. sulfuric acid will depend on whether or not the improvements in it keep ahead of new developments in the contact process. In Europe, tower systems, the Schmiedel box and Gaillard turbo-dispenser system for intensifying operations, and especially plants of Mills-Packard design, have so reduced the amount of space (and hence of investment) required per pound of sulfur burned daily that the contact process has gained only a fraction of the headway that it has won in the United States. Improvements such as these may enable the chamber process to survive. At the present time, however, the new plants being built are practically all of them contact acid plants, the construc-

tion of an old-style chamber plant by a fertilizer producer in the East in 1936 causing "considerable surprise among acid men."[13]

When the outlook in the competition of raw materials is considered, several possibilities of promise present themselves. First and foremost, of course, is the possibility of increasing the production of sulfuric acid from the "fumes" of sulfide smelters. A noted technician states:

> Careful study of the question for years leads the writer to believe that, in practically all cases, it is feasible to recover such fumes, that marketable products can be profitably produced in any locality where large smelters now operate, that the value thus produced will in many instances exceed that of the metal produced, and that no other phase of the sulphuric acid industry is so important.[14]

In an earlier edition this same authority pointed out that at that time (1917) a single company at two plants was wasting enough sulfur nearly to equal the prewar production of sulfuric acid in the United States.[15] Yet it defended damage suits and injunctions in preference to developing the outlets for the chemicals it might be able to produce. A government publication similarly reported in 1912 that "one smelter in the West discharges daily into the air 1,000 tons of sulphur in the form of sulphur dioxid, or practically one-half in weight of our total consumption for sulphuric acid and other purposes."[16] On the other hand, counterarguments are advanced that stack gases from smelter plants contain too low a percentage of sulfur dioxide to permit the production of cheap acid and that "to produce a concentration suitable for

[13] *Chemical and Metallurgical Engineering* (February 1937), Vol. XLIV, No. 2, p. 78.

[14] Allen Rogers (ed.), *Manual of Industrial Chemistry* (2 vols., 5th ed., van Nostrand, New York, 1931), Vol. I, chapter iv, "Sulphuric Acid," by William M. Grosvenor, p. 117.

[15] *Ibid.* (3d ed., 1920), p. 129.

[16] The Tariff Board, *Chemicals, Oils and Paints. Glossary on Schedule A* (Washington, D.C., 1912), p. 20.

acid manufacture would seriously reduce the metal production as well as shorten the campaign of the roasters."[17] Moreover, no market seems available unless the growth of intensive agriculture in the intermountain area creates so large a demand for fertilizers that the phosphate deposits in southeastern Idaho, northeastern Utah, and southwestern Wyoming can be developed.

A second by-product source of sulfur that is regarded as having considerable potentiality is the oil industry. It has, of course, recovered sludge acid in increasing amounts in recent years, practically every refinery of any size having a sludge conversion plant. But in 1936 a new sodium-phenolate purification plant was put into operation at El Segundo, California, which makes sulfuric acid out of the hydrogen sulfide in the refinery gases. "Similar plants for the same purpose have been contracted for at Philadelphia and Wayne, West Virginia."[18] Now if all the sulfur that is found in the petroleum consumed in the United States is recovered, "based on petroleum consumption at the 1929 rate, 173,000,000 short tons, and assuming an average content of one-half of one per cent of sulphur, there would become available from this source approximately 865,000 tons of sulphur, equivalent to 4,200,000 tons of 50° Bé. acid or more than half the entire 1930 sulphuric acid production from all sources."[19] On the other hand, it is contended that the process of eliminating sulfur from petroleum by hydrogenation, since it requires large capital expenditure, will not come into general use until the "supply of medium-boiling-point oils, such as

[17] Frank K. Cameron, "Growth of Inter-Mountain Area Handicapped by High Shipping Costs," *Chemical and Metallurgical Engineering* (March 1927), Vol. XXXIV, No. 3, p. 169.

[18] *Chemical and Metallurgical Engineering* (February 1937), Vol. XLIV, No. 2, p. 79.

[19] "1930 Sees Increase in Sulphur Mining," *Chemical and Metallurgical Engineering* (January 1931), Vol. XXXVIII, No. 1, p. 37.

gas oils becomes depleted. For several years at least hydrogenation will only be an auxiliary to existing processes,"[20] used as conditions demand conversion into high-grade gasoline and lubricants of heavy or very asphaltic oils.

Another by-product source of sulfur for sulfuric acid is coal, whether at the mines or at by-product coke ovens, gas plants, power plants, or lignite carbonization plants. Considerable amounts of sulfuric acid are already being made from coal brasses, or marcasite, which, while usually picked out by hand, are now being obtained in Kansas by an improved metallurgical concentration process in the form of pyrites satisfactory to a contact plant operator in an adjoining state. Flue-gas purification processes have been worked experimentally to utilize even the sulfur that goes to waste in the stack gases of factories and power plants, and in some cases legislation has been considered thus to mitigate the "smoke evil." In Europe, and especially in England, the spent iron oxide used to absorb the sulfur-bearing impurities in ordinary illuminating gas made from coal is an important source of sulfur, constituting in the United Kingdom in 1927 nearly a fourth of the total supply.[21] In the United States the utilization of such ferrous-sulfate waste has not yet been undertaken on a considerable scale, although in recent years a plant has been put up in the Middle West using waste ferrous sulfate to produce over 100 tons per day of monohydrate,[22] and another of equal size constructed in the East.

[20] Raymond F. Bacon, "What Is Ahead for Sulphuric Acid," *Chemical and Metallurgical Engineering* (October 1931), Vol. XXXVIII, No. 10, p. 596.

[21] *The Times Imperial and Foreign Trade and Engineering Supplement* (International Chemical and Allied Industries Number) (London, November 26, 1927), Vol. XXI, p. 6. In that year the United Kingdom derived 24 per cent of its sulfur from spent oxide, 23 per cent from brimstone, 46.3 per cent from pyrites, and 6.7 per cent from zinc concentrates.

[22] Editorial Staff, "Sustained Improvement Cheers Sulphuric Acid Producers," *Chemical and Metallurgical Engineering* (January 1935), Vol. XLII, No. 1, p. 46.

If the process proves equally applicable to the ferrous-sulfate liquors obtained in pickling iron and steel, the steel industry, like the petroleum and explosives industries, will use increasing quantities of its own reclaimed acid and less of the product of sulfuric acid producers.

There is one other development in the competition between raw materials that requires brief mention, not because it exists in this country but because of its increasing growth abroad. That is the use of calcium sulfate or gypsum as a raw material for sulfuric acid. Now gypsum is to be found almost everywhere, being especially abundant in certain strata of limestone. Its use was started in Germany during the World War when she was cut off from her normal requirements of pyrites. Among the many processes in use, the one at the Bayer plant in Leverkusen is said to be particularly successful. It consists in heating gypsum, clay, and coal, with additions of sand and slag. The resultant sulfur dioxide gases are then purified and turned into sulfuric acid in the usual way. The plant at Leverkusen is reported to have a yearly capacity of 40,000 to 50,000 tons of sulfuric acid.[28] France is likewise installing plants utilizing gypsum, and similar developments seem to be in the offing in other countries.

Let us turn now to a consideration of substitutes for sulfuric acid, intercommodity competition in the narrow sense. Developments here have been particularly numerous, consisting mainly of finding other ways to make the chemical products formerly or usually requiring sulfuric acid.

Foremost in potentiality among such processes tending to replace sulfuric acid would be the extensive use of any of the three variations of the Dorr-Liljenroth process for phosphate fertilizer manufacture. In one of its forms the process

[28] United States Department of Commerce, Bureau of Mines, *Mineral Resources of the United States, 1929* (2 vols., Washington, D.C., 1930), Part II, p. 184.

eliminates sulfuric acid entirely: Phosphate rock is put into an electric furnace and yellow phosphorus is produced. The phosphorus is then blown in vapor form, together with steam, over a catalyst at about 1000° C. Phosphoric acid and hydrogen are formed. The hydrogen is used to manufacture synthetic ammonia by, say, the Haber-Bosch process. The ammonia is combined with the phosphoric acid to form the concentrated fertilizer, ammonium phosphate. The Badische Soda und Anilin Fabrik already makes such fertilizers, called Diammonphos, in substantial quantities, having remodeled a cyanamid plant with a nitrogen capacity of 30,000 tons a year for that purpose. The phosphoric acid may be united with other compounds of nitrogen, potassium, or any desired ingredient. When, for example, phosphoric acid is used to fix ammonia, it supplants an inert carrier, the sulfate, with one that has considerable fertilizer value, thus making a concentrated fertilizer and lowering freight costs per unit of fertilizer content.

The primary limitation at the present time seems to be that of changing the fertilizer-using habits of the farmer who is used to and continues to demand superphosphates, especially the ammoniated superphosphates. Concentrated fertilizers require considerably different and more careful application. Another limitation is the expense of utilizing the electric furnace method of producing phosphorus unless cheap power can be found, either seasonal or by-product, as for example in the Tennessee Valley. Moreover, the new methods of producing fertilizers require heavy capital investment, something which the existing fertilizer concerns are reluctant, if not unable, to undertake, particularly when they must also scrap existing plant. At the present time, therefore, the wet process, that utilizing sulfuric acid, is still supreme for the making of phosphoric acid of fertilizer grade and strength, though in making phosphoric acid for food and other pur-

poses the thermal processes suffer little or no competition from the the wet method. But proponents of both the electric- and blast-furnace processes are continually pushing costs lower, and it is not inconceivable that one system or the other may eventually displace the wet process entirely, especially where strong phosphoric acid is needed.

Another development of importance to the fertilizer industry is that by which gypsum, ammonia, and carbon dioxide are used on the chemical principle of double decomposition to produce ammonium sulfate. While not used so extensively in the United States, in Germany and in the United Kingdom large quantities of gypsum or anhydrite are thus utilized, the resultant ammonium sulfate frequently being further treated with Chile saltpeter or sodium nitrate to produce ammonium nitrate. Again the use of sulfuric acid is eliminated.

In the petroleum industry mention has already been made of processes whereby the sulfur found in many oils may become a raw material for sulfuric acid. But recent improvements in processes not only have reduced but apparently will continue to reduce the amount of sulfuric acid required. Traditionally, the sulfur content of gasoline is supposed to be not over one-tenth of one per cent, the treatment deemed necessary costing the industry $50,000,000 per year[24] in loss of product, reduction in anti-knock properties, and cost of sulfuric acid used. Recent research not only has established the fact that modern motors can utilize without damage gasoline of considerably higher sulfur content but has devised methods of operation whereby the use of sulfuric acid is eliminated entirely, for example, by treating gasoline in the vapor phase with clay, by treating it with zinc chloride, by using solvent extraction methods for making lubricating oil, or by adding gum and color inhibitors. Moreover, when the sulfur content

[24] "1930 Sees Increase in Sulphur Mining," *Chemical and Metallurgical Engineering* (January 1931), Vol. XXXVIII, No. 1, p. 36.

of the oil is reduced by the process of hydrogenation (and the resultant hydrogen sulfide made into sulfuric acid), the amount of sulfuric acid consumed is reduced to that necessary only for the removal of gum-forming constituents.

The use of sulfuric acid to make other acids is also beset with competition. Mention has already been made of the way in which nitric acid is produced by the oxidation of ammonia, rather than by the aid of sulfuric acid, even in the sulfuric acid plants themselves. But nitric acid obtained in this way is already produced so cheaply as to be used in acidulating phosphate rock, where it adds valuable nitrogen content in addition to acting as carrier. The major factor in favor of sulfuric acid here continues to be consumer inertia, plus the difficulty and expense of shipping nitric acid to the small superphosphate plants scattered over the South. If farmers were educated to use concentrated fertilizers, large plants making their own nitric acid and phosphoric acid might be established and the use of sulfuric acid in fertilizer manufacture considerably reduced.

Chemical synthesis has dealt reverses to the sulfuric acid industry in other ways. Formic and acetic acids, alcohols, and various other organic compounds are being synthesized by catalytic processes. Even hydrochloric acid is being produced in appreciable quantities by the direct union of chlorine and hydrogen, the former being a by-product in the electrolytic-caustic-alkali industry. Thus the contention that sulfuric acid consumption is an index of chemical and industrial progress may be said in some respects to be true to the extent that increases in progress are measured by *decreases* in the consumption of sulfuric acid. The trend of present chemical research is to find methods of chemical manufacture making sulfuric acid unnecessary. Catalysis, synthesis, high pressures, high temperatures—such are the tools of modern chemical transformations.

Among minor developments mention should be made of the fact that salt cake, which used to be made by the action of sulfuric acid on salt, is now produced in appreciable quantities, especially in Germany, by the action of salt on waste magnesium sulfates. Moreover, in the pickling of iron and steel, increasing use has been made in recent years of inhibitors and electrochemical methods which require little acid.

In the future, therefore, sulfuric acid will probably play a much smaller role in bringing about the chemical transformation of industrial processes than it has in the past. Prior to 1880 the sulfuric acid industry, together with the Leblanc alkali industry, virtually made up the entire chemical industry. Today in the United States its place has come to be a relatively small one. In 1929, for example, total sales aggregated $45,573,245. While by far the most important of the scores of acids listed, it constituted less than half of their aggregate value, which was $98,619,871. But the acids constituted but one of nine groups of products listed under "chemicals not elsewhere classified," whose aggregate production was reported in 1929 as worth $738,048,386, or more than sixteen times that of the sulfuric acid sold. But "chemicals not elsewhere classified" constituted a relatively minor part of Group VI, listed in the Census of Manufactures and called "Chemicals and Allied Products." These industries in 1929 employed 279,198 workers in 8,224 establishments, and put out products valued at $3,702,672,063, a figure more than eighty times the value of the sulfuric acid sold.

Truly, sulfuric acid in modern times is only one among many chemicals. But historically the sulfuric acid industry, as we have seen, was the primary agent through which was effected that chemical transformation of industrial processes and industrial economics known as the chemical phase of the Industrial Revolution.

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